

# **EXHIBIT 11**

**FILED UNDER SEAL**

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UNITED STATES DISTRICT COURT  
DISTRICT OF DELAWARE

TQ Delta, LLC,

Plaintiff,

v.

2Wire, Inc.

Defendant.

Case No. C.A. No. 1:13-cv-01835-RGA

Jury Trial Demanded

CORRECTED REBUTTAL EXPERT REPORT OF DR. TODOR COOKLEV  
REGARDING VALIDITY OF THE FAMILY 3 PATENTS

CONFIDENTIAL - ATTORNEYS' EYES ONLY

I declare under penalty of perjury that the following is true and correct.

JANUARY 4, 2019

DATE

A handwritten signature in black ink, appearing to read 'T Cooklev', written over a horizontal line.

Todor Cooklev, Ph.D.

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## I. INTRODUCTION

1. My name is Dr. Todor Cooklev, and I have been retained by TQ Delta LLC (“TQ Delta”).

2. I have been asked to prepare this report (“Rebuttal Report”) in connection with the above captioned District Court action between TQ Delta LLC and 2Wire, Inc. (“Defendant”). I have reviewed the report by Dr. Krista Jacobsen (“the Jacobsen Report”) submitted in this litigation on November 28, 2018. I address the Jacobsen Report in detail below. Specifically, I have been asked to opine on Dr. Jacobsen’s allegations that claim 1 of U.S. Patent No. 8,276,048 (“the ’048 patent”), claim 5 of U.S. Patent No. 7,836,381 (“the ’381 patent”), claim 13 of U.S. Patent No. 7,844,882 (“the ’882 patent”), and claim 19 of U.S. Patent No. 8,495,473 (“the ’473 patent”) are invalid. I will be referring to the above-mentioned claims, collectively, as the Asserted Claims, and to the above-mentioned patents, collectively, as the Asserted Patents or the Family 3 Patents.

3. My qualifications were described in detail in Section II of my opening report on the infringement of the Family 3 Patents submitted on November 28, 2018 (“Cooklev Inf. Report”), as well as in my curriculum vitae, which was attached to that Report as Exhibit 1.

4. I also incorporate my discussion of the Asserted Claims and claim constructions from my opening report. *See, e.g.*, Cooklev Inf. Report at §§ VII.D-F, X.

5. In coming to my conclusions, I reviewed the materials identified in Exhibit 1 to this Report, as well as all materials referenced in this Report.

6. As detailed below, based upon my personal knowledge, expertise, and the review and analysis I have performed to date, I have formed the following opinions:

7. Claim 1 of the '048 patent is valid. The claim covers patentable subject matter, is not obvious in view of the prior art as applied by Dr. Jacobson. The claim is supported by the specification's written description, enabled, and definite.

8. Claim 5 of the '381 patent is valid. The claim covers patentable subject matter, is not obvious in view of the prior art as applied by Dr. Jacobson. The claim is supported by the specification's written description, enabled, and definite.

9. Claim 13 of the '882 patent is valid. The claim covers patentable subject matter, is not obvious in view of the prior art as applied by Dr. Jacobson. The claim is supported by the specification's written description, enabled, and definite.

10. Claim 19 of the '473 patent is valid. The claim covers patentable subject matter, is not obvious in view of the prior art as applied by Dr. Jacobson. The claim is supported by the specification's written description, enabled, and definite.

11. I set forth below the bases and reasoning for these opinions. Specifically, I explain why Dr. Jacobson's opinions fail to invalidate the Asserted Claims on any basis. In doing so, I explain why each alleged prior art reference does not invalidate the Asserted Claims, by obviousness, and why the Asserted Claims are not invalid for lack of written description or enablement, or for indefiniteness.

12. I based this Report on information currently available to me. I reserve the right to expand, modify, or supplement my Report based on additional information, to the extent that information was not provided to me before this Report is due. I further

reserve the right to expand, modify, and/or supplement this Report and my opinions in response to matters raised by Defendant and/or Defendant's expert(s), opinions provided by other defendants and/or their expert(s) in related matters, or in view of relevant orders and findings by the Court.

13. In this Report, I cite to various documents and testimony. These citations are meant to be exemplary, and not exhaustive. Citations to documents or testimony are not intended to signify that my conclusions or opinions are limited to the cited sources, or supported by the cited sources only.

14. I expect to be available for deposition and to testify at trial in the above captioned actions. I reserve the right to perform demonstrations and use animations, demonstratives, and/or other physical evidence at trial. I expressly reserve the right to offer opinions at trial and/or in one or more supplemental reports on subjects raised in my deposition, as well as on matters raised by Dr. Jacobsen or by Defendant(s) in any subsequent report, at deposition, or at trial.

15. I am being compensated at \$400 per hour, which is my standard hourly consulting rate, plus reasonable expenses. I have not received any additional compensation for my work on this case, and no part of my compensation is dependent on my conclusions or on the outcome of the above captioned actions.

## **II. APPLICABLE LEGAL PRINCIPLES**

16. I have reviewed Dr. Jacobsen's statements of legal standards that Dr. Jacobsen purportedly applied in forming her opinions. While I generally agree with the statements on the law, the summarizations overlook several important points that result

in misleading opinions. I have been informed by TQ Delta's counsel about the legal principles that I understand control the issues that Dr. Jacobsen opined on and which I rebut. I have applied these legal standards to the facts, circumstances, and materials considered, along with my experience, in reaching the conclusions and opinions expressed in this Report.

**A. Presumption of Validity**

17. It is my understanding that the claims of an issued U.S. patent are presumed valid. I further understand that the party challenging a patent claim's validity bears the burden of proving that claim invalid by clear and convincing evidence.

18. I understand that the standard for clear and convincing evidence is higher than the preponderance-of-evidence standard that is used to determine infringement. I am informed that the clear-and-convincing evidence standard requires an abiding conviction that the truth of a fact is highly probable.

19. I understand that this burden may be more difficult for a Defendant to meet if prior art was considered by the Examiner during the original prosecution of an Asserted Patent.

**B. Anticipation**

20. I understand the following principles apply for determining anticipation under 35 U.S.C. § 102. A patent claim is anticipated by prior art when each element of the claim is present within a single prior art reference. In addition, each element of the claim must be arranged in the prior art as it is in the claim. An element may be either

expressly disclosed or inherent in the prior art. A claim element is only inherent if it is necessarily present in the reference. I further understand that the possibility, even if probable, that an element may result from a certain set of circumstances – that is, an element *might* be present – is not sufficient to establish inherency.

21. I have been informed that, although anticipation cannot be established through a combination of references, additional references may be used to interpret the allegedly anticipating reference by, for example, indicating what the allegedly anticipating reference would have meant to one of ordinary skill in the art. For the claim to be anticipated, however, these other references must make clear that the missing descriptive matter in the patent claim is necessarily or implicitly present in the allegedly anticipating reference, and that it would be so recognized by one of ordinary skill in the art.

### **C. Obviousness**

22. I understand the following principles apply for determining obviousness under 35 U.S.C. § 103. A claim may be invalid as obvious if the difference between the claimed subject matter and one or more prior art references are such that the subject matter as a whole would have been obvious at the time the invention was made to a person of ordinary skill in the art (“POSITA”). The following factors must be found and considered in determining obviousness: (1) the scope and content of the prior art; (2) the differences between the art and the claims at issue; (3) the level of ordinary skill in the art; and, (4) objective evidence of non-obviousness, which is also referred to as secondary considerations.

23. It is not enough that the prior art references can be combined; there must be a motivation to one of ordinary skill in the art to arrive at the claimed invention. But I also understand that motivation may not be gleaned from impermissible hindsight reasoning. That is, the reason to combine the prior art to arrive at the claimed invention cannot be based in whole or in part on the inventors' own disclosure.

24. I understand that assessing which prior art references to combine and how they may be combined to match the asserted claim may not be based on hindsight reconstruction. Hindsight reconstruction is using the patent itself as a road map for recreating the invention. In assessing obviousness, only what was known before the invention was made can be considered. I also understand that one important guard against such hindsight reconstruction is a determination whether a person of ordinary skill in the art would have been motivated, taught, or suggested to combine the relevant techniques of the prior art to duplicate the patent claims at the time of the patented invention.

25. I understand that obviousness cannot be predicated on the mere identification in the prior art of individual components of claimed limitations. It is not appropriate to pick and choose among the individual elements of assorted prior art references to recreate the claimed invention, but rather, there must be some teaching or suggestion in the references to support their use in the particular claimed combination.

26. I understand that it is the Defendant's burden to prove that a person of ordinary skill in the art would have been motivated to combine the prior art references. I understand that the motivation to combine must be supported by evidence and



articulated explanation. When considering obviousness, I understand that it is insufficient to simply say that a skilled artisan, once presented with a combination of references, would have understood that they could be combined.

27. Rather, the Defendant must show that the skilled artisan would have been motivated to make the combinations or modification of prior art to arrive at the claimed invention. Conclusory statements alone are insufficient, and any obviousness analysis must be supported by a reasoned explanation as to why a person of ordinary skill in the art would have been motivated to combine the prior art. For example, “common sense” or “intuition” alone cannot support a motivation to combine without explaining why they would lead a skilled artisan to solve the problem at hand with the particular elements of the claimed invention.

28. I understand that, to determine the scope and content of the prior art, I must consider whether the prior art was reasonably relevant to the particular problem the inventors faced in making the claimed invention.

29. To determine whether any material differences existed between the scope and content of the prior art and each asserted claim, I must consider the claimed invention as a whole to determine whether or not the claim would have been obvious in light of the prior art. If the prior art discloses all the elements in separate references, I must consider whether it would have been obvious to combine those references. I understand that a claim is not obvious just because all elements of a claim already existed.

30. I understand that a motivation to conduct further testing or research that may lead to the claimed invention does not necessarily render a claim obvious. I further understand that an invention is not necessarily rendered obvious simply because it was obvious to try a certain combination.

31. Secondary considerations may also impact a determination of obviousness, provided that there is some nexus or link between the claimed invention and the secondary factors considered. I further understand that any secondary factors that may prove instructive in determining non-obviousness should be considered. The following are examples:

- (1) a long-felt, but unmet need for the invention;
- (2) prior art teaching away from the invention;
- (3) failure of others to make the invention;
- (4) praise for the invention;
- (5) commercial success;
- (6) copying of the invention;
- (7) initial skepticism for the invention;
- (8) licensing;
- (9) whether the invention proceeded in a direction contrary to accepted wisdom in the field.

32. I understand that the inquiry into secondary considerations is a means to check hindsight analysis. I am informed that it is impermissible to use hindsight and that it is improper to focus on just one portion or element of the invention, as opposed to the invention as a whole.

33. I also understand that when prior art teaches away from combining prior art references, the discovery of a successful way to combine them is unlikely to be obvious. Prior art teaches away from an invention when a person of ordinary skill would be discouraged or diverted from following the path leading to the invention because of the prior art. I also understand that if a proposed combination would require modification of prior art and that modification would render the prior art unsatisfactory for its intended purpose, then there is no suggestion or motivation to make the proposed combination and modification.

**D. Written Description**

34. I understand the following legal principles apply to assessing whether a patent is invalid for not meeting the written description requirement in 35 U.S.C. § 112, ¶ 1. The written description requirement evaluates whether the patent applicant had possession of the full scope of the claimed invention at the time the patent application was filed. This evaluation is made from the perspective of one of ordinary skill in the art. Claims may be broader than the embodiment or embodiments identified in the specification, and the specification may contain adequate written description of a broadly claimed invention without expressly describing every embodiment the claim encompasses.

**E. Definiteness and Enablement**

35. I also understand that claims must be particular and distinct, which is also referred to as a definiteness requirement in 35 U.S.C. § 112, ¶ 2. This definiteness requirement provides that a patent applicant must particularly point out and distinctly

claim the subject matter that the applicant regards as the invention. The definiteness standard is one of reasonableness under the circumstances. In other words, in light of the teachings of the prior art and of the particular invention, the definiteness inquiry is whether the claims inform those skilled in the art about the scope of the invention with reasonable certainty.

36. The enablement requirement requires the inventor to describe his or her invention in a manner that would allow others in the industry to make and use the invention. To analyze enablement, one needs to take into account the knowledge of a POSITA.

37. I understand that a patent need not teach, and preferably omits, what is well known in the art. I also understand that resort to material outside of the specification in order to satisfy the enablement requirement is permissible because it makes no sense to encumber the specification of a patent with all the knowledge of the past concerning how to make and use the claimed invention. I further understand that the fact that some experimentation is necessary does not preclude enablement, but that any required experimentation must be reasonable. Some trial and error is permissible.

38. Further, I have been informed that enablement does not require the inventor to foresee every means of implementing an invention. Finally, I am informed that the specification need not necessarily describe how to make and use every possible variant of the claimed invention, for the artisan's knowledge of the prior art and routine experimentation can fill in any gaps, interpolate between embodiments, and even extrapolate beyond the disclosed embodiments.

**F. Claiming Priority to A Provisional Application**

39. I understand that a patent may be given the prior art date of the patent's provisional application. I am informed that a reference patent is entitled to claim the benefit of the filing date of its provisional application if the disclosure of the provisional application provides support for the claims in the reference patent.

**III. PERSON OF ORDINARY SKILL IN THE ART**

40. I defined a person of ordinary skill in the art with respect to the subject matter of the Family 3 Patents in Section VI.A of my Opening Infringement Report. I incorporate that definition by reference. *See* Cooklev Inf. Report at § VI.A.

**IV. BACKGROUND OF DSL TECHNOLOGY AND INVENTION**

41. I set forth a background of DSL communications, error correction, interleaver and deinterleaver memory, and the inventions of the Asserted Patents alongside with their benefits in Sections VII.A-F of my Opening Infringement Report. *See* Cooklev Inf. Report at §§ VII.A-F. I incorporate those sections by reference.

**A. Interleaver Memory and Deinterleaver Memory in Prior Art Systems**

42. DSL systems, such as, for example, ADSL2/2+ standards known at the time of the inventions, specify dedicated interleaving memory requirements in each transceiver separately for upstream and downstream transmission (i.e., in each direction separately). More specifically, an ADSL2/2+ ATU-C is required to have a specified amount of dedicated interleaving memory for downstream data transmission and separately and independently have a specified amount of dedicated interleaving memory for upstream data reception. ADSL2/2+ specifies that the ATU-C must have

enough dedicated memory for downstream interleaving to interleave codewords sizes of  $N_{fec} = 255$  bytes with an interleaver depth of  $D=64$ . This corresponds to  $N_{fec} \times D = 255 \times 64 = 16,320$  octets of dedicated interleaving memory for downstream. Likewise, ADSL2/2+ specifies that the ATU-C must separately have enough dedicated memory for upstream deinterleaving to deinterleave codewords sizes of  $N_{fec} = 255$  bytes with an deinterleaver depth of  $D=8$ . This corresponds to  $N_{fec} \times D = 255 \times 8 = 2,048$  octets of dedicated deinterleaving memory for upstream. The total interleaving + deinterleaving memory requirement for an ATU-C is therefore approximately  $16K + 2K = 20K$ . These requirements are specified (or derived from values provided) in Tables 7-7, 7-8, 7-9 and 7-10 of G.992.3/2002.

43. In the same manner, an ADSL2/2+ ATU-R is required to have a specific amount of dedicated interleaving memory for downstream data reception and separately have a specific amount of dedicated interleaving memory for upstream data transmission. Like the ATU-C, ADSL2/2+ specifies that the ATU-R must have enough dedicated memory for downstream deinterleaving to deinterleave codewords sizes of  $N_{fec} = 255$  bytes with an deinterleaver depth of  $D=64$ . This corresponds to  $N_{fec} \times D = 255 \times 64 = 16,320$  octets of dedicated deinterleaving memory for downstream. Like the ATU-C, ADSL2/2+ specifies that the ATU-R must have enough memory for upstream interleaving to interleave codewords sizes of  $N_{fec} = 255$  bytes with an interleaver depth of  $D=8$  for upstream. This corresponds to  $N_{fec} \times D = 255 \times 8 = 2,048$  octets of dedicated interleaving memory. The total deinterleaving + interleaving memory requirement for

an ATU-R is therefore approximately  $16,320 + 2,048 = 18,368$  octets. These requirements are specified in Tables 7-7, 7-8, 7-9 and 7-10 of G.992.3/2002.

44. The ADSL2/2+ standards do not specify or enable memory sharing between the interleaver and the deinterleaver in a single transceiver. Furthermore, since ADSL2/2+ specify that the ATU-C downstream interleaver and the ATU-R downstream deinterleaver have the same amount of memory (i.e., ~16K octets) there are no messages specified (or ever needed) to negotiate the amount of memory to be allocated to the interleaver (in the ATU-C) or to the deinterleaver (in the ATU-R). Likewise, since ADSL2/2+ specify that the ATU-R upstream interleaver and the ATU-C upstream deinterleaver have the same amount of memory (i.e. ~2K octets) there are no messages specified (or ever needed) to negotiate the amount of memory to be allocated to the interleaver (in the ATU-R) or to the deinterleaver (in the ATU-C).

45. Prior to the inventions disclosed in the Family 3 patents, an amount of memory available to an interleaver was predetermined and an amount of memory available to a deinterleaver was predetermined. Those systems were incapable of sharing memory between an interleaving and deinterleaving function based on a message.

#### **B. Shared Interleaver and Deinterleaver Memory in the Family 3 Patent Inventions**

46. The below examples illustrate how, even if one of the transceivers provided more memory than the minimum specified by a standard, the interleaver memory and the deinterleaver memory in a single transceiver had been implemented in

prior art systems before the inventions of the Family 3 patents in comparison with how the shared memory can be allocated to an interleaver and a deinterleaver according to the inventions of the Family 3 patents.

47. Generally, a transceiver (e.g., VTU-R) with a larger dedicated deinterleaver memory than is required could at most determine whether a transceiver (e.g., VTU-O) at the other line of the line can also support a larger amount. But, if the VTU-O does not support a larger amount than is required, however, the extra deinterleaver memory of the VTU-R is simply not used. For example, it is not available to be used for the upstream interleaver function. The examples described below illustrate this concept.

48. Example 1 (Prior Art Systems). VTU-O (30,000 octets of dedicated downstream interleaver memory; 30,000 octets of dedicated upstream deinterleaver memory). VTU-R (40,000 octets of dedicated downstream deinterleaver memory; 20,000 octets of dedicated upstream interleaver memory).

Legend:



dedicated downstream memory (interleaver memory for VTU-O,  
deinterleaver memory for VTU-R)



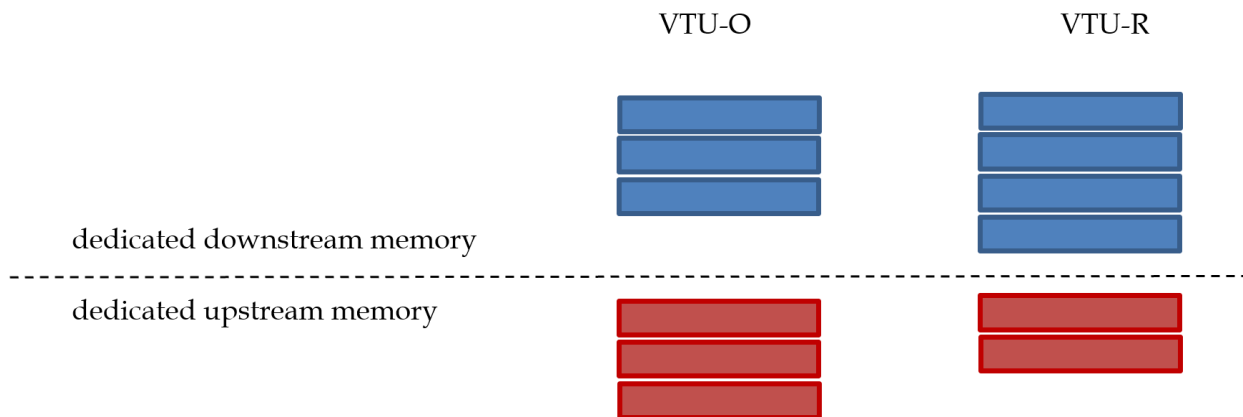
dedicated upstream memory (interleaver memory for VTU-R,  
deinterleaver memory for VTU-O)



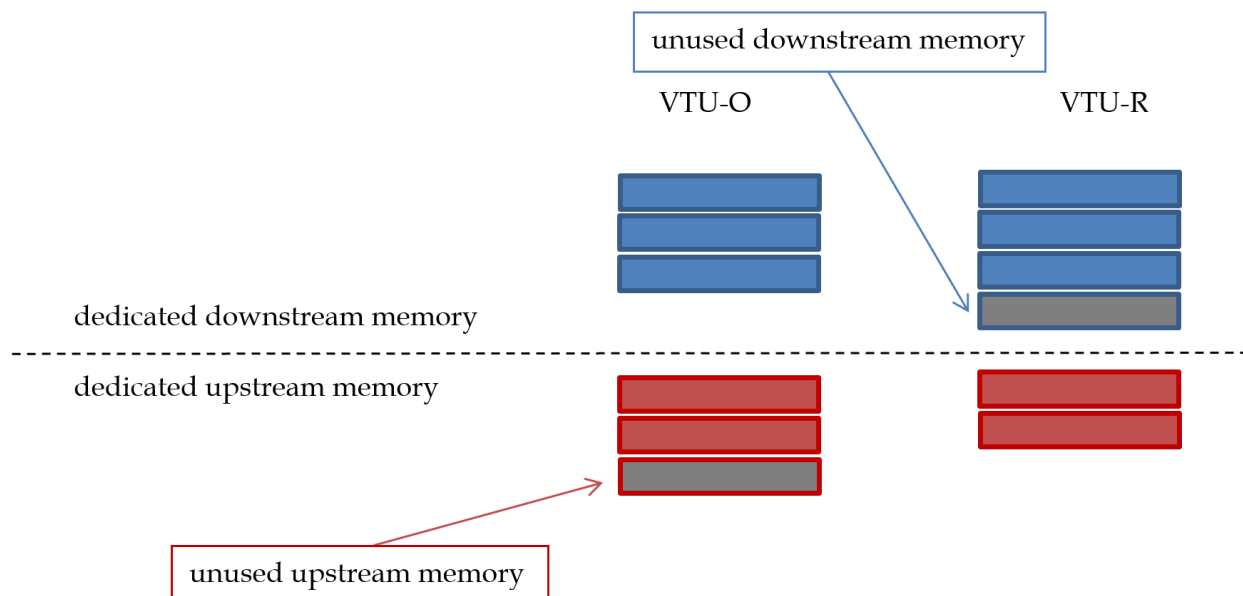
 unused memory

Each rectangle represents 10,000 octets of memory.

49. Capabilities (maximum memory supported):



50. Even if each transmitter exchanged their memory capabilities in each direction, the smaller of the transmitter and receiver capabilities in each direction would need to have been chosen. Because the smaller capability is selected, this results in a maximum possible memory allocation as shown below.



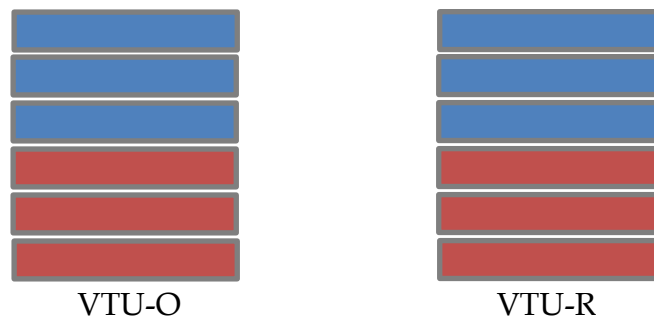
51. Also, because the smaller of the capabilities of the transmitter or receiver are selected in each direction, unused memory for one function in a transceiver cannot be used for another function, e.g., unused dedicated deinterleaver memory in the VTU-R cannot be used for the interleaving function. In the example above, 10,000 octets of deinterleaver memory within the VTU-R and 10,000 octets of deinterleaver memory in the VTU-O would never be used.

52. Under such implementation even though the VTU-R learned about the VTU-O's capabilities downstream, it could not use 10,000 octets of its 40,000 octets of memory that was dedicated to the downstream deinterleaver. Likewise, even though the VTU-O learned about the VTU-R's capabilities upstream, it could not use 10,000 octets of its 30,000 octets of memory that was dedicated to the upstream deinterleaver.

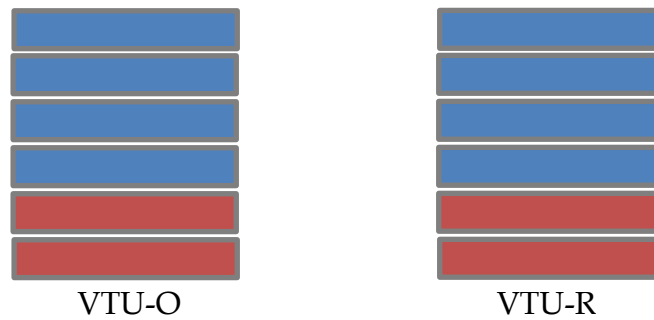
53. In this example, if a service provider is providing a VDSL2 service that requires 30,000 octets of memory in each transceiver for the downstream service and 20,000 octets of memory in each transceiver for the upstream service, the transceivers would be able to provide that service. If, however, a service provider is providing a VDSL2 service that requires 30,000 octets of memory in each transceiver for the downstream service and 30,000 octets of memory in each transceiver for the upstream service, the transceivers would NOT be able to meet the requirements of the service.

54. The above example can be contrasted with an example implementing the claimed allocation of memory between an interleaving function and a deinterleaving function according to the inventions of the Family 3 patents (Example 2, *infra*).

55. Example 2 (Family 3 Patents). Each transceiver supports a total of 60,000 octets of shared interleaver/deinterleaver memory. If the service provider desires to provide a VDSL2 service that requires 30,000 octets of memory in each transceiver for the downstream service and 30,000 octets of memory in each transceiver for the upstream service, the 60,000 octets of memory in each transceiver could be allocated between the interleaver and deinterleaver functions such that 30,000 octets in each transceiver are used for the downstream path and 30,000 octets are used for the upstream path as illustrated below.



56. On the other hand, if the service provider desires to provide a VDSL2 service that requires 40,000 octets of memory in each transceiver for the downstream service and 20,000 octets of memory in each transceiver for the upstream service, the 60,000 octets of memory in each transceiver could be allocated between the interleaver and deinterleaver functions such that 40,000 octets in each transceiver are used for the downstream path and 20,000 octets are used for the upstream path as illustrated below.



57. Therefore, unlike the prior art systems where 10,000 octets of memory are unused and the service provider could not provide the service to the customer, when shared memory, which can be allocated between the interleaver function or deinterleaver function, is used, memory that would otherwise go unused can be allocated to one function or the other depending on messages that are, in part, dependent on the service requirements. As illustrated by these examples, the VTU-R is capable of allocating 10,000 octets of its memory to the upstream interleaving function at one time but allocating the same 10,000 octets of its memory to the downstream deinterleaving function at another time. This provides flexibility that enables the transceivers to meet different service requirements.

**C. References Cited in Jacobsen Report are Consistent with Implementations that Precede the Inventions of Family 3 Patents**

58. Dr. Jacobsen asserts that prior art systems were capable of providing “shared memory that the transceiver can partition between its interleaver and deinterleaver on a per-connection basis. Use of shared memory for interleaving and

deinterleaving, including in DSL, was well known before the priority date of the Family 3 patents.” See Jacobsen Report at ¶ 72. This is incorrect.

59. To support her argument, Dr. Jacobsen cites to several prior art references. Yet, none of these references discloses what she asserts that they do.

60. Berkmann does not disclose providing “shared memory that can be partitioned between its interleaver and deinterleaver on a per-connection basis,” as Dr. Jacobsen asserts. See Jacobsen Report at ¶ 72. While Berkmann describes using “a combined interleaving and deinterleaving circuit,” (*id.* at Abstract), it further explains that “[o]nly the interleaving function  $\alpha(i)$  (or, alternatively, the inverse deinterleaving function  $\alpha^{-1}(i)$ ) must be implemented, but not both functions” (*id.* at ¶ 102). Without much further analysis of Berkmann needed, it is clear that regardless of whether the “combined interleaving and deinterleaving circuit” meets a definition of shared memory as construed by the Court (and it does not), it is not being partitioned *between* the interleaving function and the deinterleaving function, and it is not being partitioned on a *per-connection* basis. At most, Berkmann discloses a circuit for carrying out interleaving *or* deinterleaving, but not both, at the same time, which does not disclose shared memory as construed by the Court.

61. Fadavi-Ardekani does not disclose providing “shared memory that can be partitioned between its interleaver and deinterleaver on a per-connection basis,” as Dr. Jacobsen asserts. See Jacobsen Report at ¶ 72. As explained in, for example, Sections VI.C.1 and VI.C.2, *infra*. Fadavi only teaches that the interleaver and deinterleaver are each provided with a size of memory that “is derived by multiplying the maximum

codeword length by the maximum interleaver depth.” Fadavi at 7:9-10. Thus, Fadavi teaches using dedicated memories for the interleaving function and deinterleaving function. Also, as explained in those sections, the disclosed “ping-pang” operation does not meet the shared memory requirement, nor is it the memory assigned on per-connection basis.

62. Kang does not disclose providing “shared memory that can be partitioned between its interleaver and deinterleaver on a per-connection basis,” as Dr. Jacobsen asserts. *See* Jacobsen Report at ¶ 72.

63. Mazzoni does not disclose providing “shared memory that can be partitioned between its interleaver and deinterleaver on a per-connection basis,” as Dr. Jacobsen asserts. *See* Jacobsen Report at ¶ 72. As explained in, for example, Sections VI.B.1, VI.B.3.a, and VI.B.3.b, *infra*, Mazzoni describes the assignment of interleaver memory and deinterleaver memory for predefined data rate pairs (services) by using predefined I and M parameter values for its interleaving means, and predefined I’ and M’ parameter values for deinterleaving means for each data rate pair (i.e., service). *Id.* at 5:24-30. Also, as explained in the cited sections, the assignment is performed at the time of an installation of the modem, and not per-connection basis. *See* Mazzoni at 6:51-61.

64. Voith does not disclose providing “shared memory that can be partitioned between its interleaver and deinterleaver on a per-connection basis,” as Dr. Jacobsen asserts. *See* Jacobsen Report at ¶ 72. As explained in Sections VI.E.1 and VI.E.2, *infra*.

Voith merely teaches use of an external memory. Voith does not teach that the external memory is “shared memory.”

## **V. THE ASSERTED CLAIMS OF THE FAMILY 3 PATENTS ARE VALID**

65. As set forth in this Rebuttal Report, it is my opinion and conclusion that each Asserted Claim of the Family 3 Patents are not invalid in view of the alleged prior art as asserted in the Jacobsen Report.

66. In performing my analysis, I have compared the limitations of each Asserted Claim with the disclosure in the alleged prior art references. I have also considered the scope and content of the prior art, the differences between the prior art and the claimed invention, the level of ordinary skill in the art at the time of the invention, and whether the differences are such that the claimed invention as a whole would have been obvious to one of ordinary skill in the art at the time the invention was made.

67. In my analysis below, I have applied, where applicable, the Court’s claim construction. *See* Cooklev Inf. Report at § X.

### **A. Claim 19 of the ‘473 patent is valid under 35 U.S.C. § 112, ¶2**

68. Dr. Jacobsen asserts that:

[C]laim 19 of the ‘473 patent is indefinite. Claim 19 recites the limitation ‘wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.’ One of ordinary skill in the art would not have known with reasonable certainty whether a portion of the memory actually has to be allocated to an interleaving function at one time, and a deinterleaving function at another, or whether the mere possibility that some portion of the memory could possibly be allocated to

the interleaving or deinterleaving function suffices to meet the claim language.”

Jacobsen Report at ¶ 151 (emphasis in original).

69. I disagree with Dr. Jacobsen’s conclusion as well as with the arguments she presents to support her position as explained below.

70. Dr. Jacobsen’s arguments are premised on the assertion that the “Court determined that this language should have its plain meaning during claim construction.” Jacobsen Report at ¶ 151. While it is true that the Court gave plain meaning to this claim term, the Court also provided context for this claim language, which Dr. Jacobsen ignores in her analysis. Specifically, the Court noted:

The claim language does not require that the message specify amounts of memory. The disputed term’s language requires that the amount of memory depend on the message’s contents, but it does not require that the message’s contents themselves actually specify amounts of memory.

Claim Construction Memorandum for Family 3 Patents (Dec. 18, 2017), D.I. 445, (“CC Memo”) at p. 10.

71. Dr. Jacobsen ignores the Court’s guidance in reaching her conclusion that:

It is not clear from the intrinsic record, however, whether this allocation actually has to happen, at some point, in order for a device to infringe. For example, a system could use a shared memory in such a way that it is theoretically possible that a portion of the memory is allocated to a deinterleaver or an interleaver, depending on the message, but it might not actually ever happen in practice. One of ordinary skill in the art would not have understood whether such a system would infringe claim 19 of the ’473 patent.

Jacobsen Report at ¶ 152.

72. As an initial matter, Dr. Jacobsen refers to the “claims, specification, and file history” as purportedly supporting her unfounded argument. Yet, Dr. Jacobsen



does not explain how either supports her conclusion. In fact, Dr. Jacobsen does not quote from or cite to the claims, specification, or the file history.

73. In any event, Dr. Jacobsen's assertion indicates that she misunderstands the scope of an apparatus claim that defines structure in functional terms. I understand that an apparatus claim is infringed when the accused apparatus is capable of infringement. Therefore, the answer to Dr. Jacobsen's question about the scope of the claim is that the claimed allocation does not actually have to happen in order for the claim to be infringed. Rather, the claim is infringed by transceivers that are capable of allocating at least a portion of the memory to the interleaving function or the deinterleaving function at any one particular time depending on the message.

74. A POSITA would understand that this claim language, as even the Court agreed, requires only that the function to which the portion of memory is allocated at one particular time depends on the message's contents. The use of the term "may" does not render the scope of the claim indefinite. Rather, "may" is the most appropriate term given that the claim provides two possibilities on its face – that, depending on the message, (1) the portion of memory be allocated to the interleaver function at a particular time, or (2) the portion of memory be allocated to the deinterleaver function at a particular time. A transceiver that is not capable of allocating at least some portion of memory to interleaving at one time and allocating that same portion to deinterleaving at another time would not infringe. A transceiver that is capable of doing so, such as the Accused Products, would infringe. Thus, claim 19 the '473 patent

informs those skilled in the art about the scope of the invention with reasonable certainty.

75. I note that 2Wire did not raise this indefiniteness argument during claim construction, and in fact proposed a claim construction that literally included the phrase “memory may be allocated.” CC Memo at 9-10 (2Wire’s proposed construction: “wherein at least a number of bytes within the memory may be allocated to the [first] interleaving function or the [second interleaving / deinterleaving] function at any one particular time depending on the amounts of memory specified in the message.”). While I do not agree that 2Wire’s proposed claim construction is accurate, 2Wire and Dr. Jacobsen had no problem proposing a construction that included this phrase verbatim. One must assume that 2Wire would not have proposed an indefinite construction for this claim element.

76. For the foregoing reasons, it is my opinion that claim 19 of the ’473 patent is definite and that Dr. Jacobsen has not proven otherwise.

**B. Written Description and/or Enablement under 35 U.S.C. § 112, ¶1**

77. The Court construed the term “the shared memory allocated to the [deinterleaver / interleaver] is used at the same time as the shared memory allocated to the [interleaver / deinterleaver]” to mean “the deinterleaver reads from, writes to, or holds information for deinterleaving in its respective allocation of the shared memory at the same time as the interleaver reads from, writes to, or holds information for interleaving in its respective allocation of the shared memory.” Dr. Jacobsen contends

that this term lacks written description and enablement. Jacobsen Report at ¶ 153. I disagree.

78. Dr. Jacobsen acknowledges that “[t]he specification describes sharing resources, such as memory and processing power, as well as ways of allocating those shared resources.” Jacobsen Report at ¶ 154. She asserts, however, that the specification purportedly does not “describe or explain how shared memory that is allocated to an interleaver and a deinterleaver can be used at the same time, or even what “used at the same time” even means. As an initial matter, I understand that there is no requirement that the specification describes what “used at the same time means” as long as the plain meaning of the claim language is understood in view of the specification. That is the case here. “Used at the same time” is a common and well understood term in general and one of skill in the art understands what it means to “use” memory. In any event, 2Wire agreed to the Court’s construction of this term. CC Memo at p. 9.

79. Further, a POSITA would know how memory that is allocated to two different functions can be “used at the same time.” While Dr. Jacobsen asserts that one of skill in the art would not know how this can be done, she does not explain why this is so. In any event, I disagree with her unsupported assertion. The simultaneous use of memory by multiple functions was a well-known process at the time of the inventions. A POSITA at that time would know how two or more functions can simultaneously use the same memory by storing information for a first function at the same time that information for a second function is stored in the memory, or written to the memory, or

read from the memory. This is inherent in any multi-threaded operation that uses the same memory.

80. Dr. Jacobsen asserts that the specification does not explain how memory allocated to an interleaver and memory allocated to a deinterleaver can be used at the same time. Jacobsen Report at ¶ 154. I understand that such explanation in the specification is not required. Rather, I understand that a patent need not teach, and preferably omits, what is well known in the art. I also understand that resort to material outside of the specification in order to satisfy the enablement requirement is permissible because it makes no sense to encumber the specification of a patent with all the knowledge of the past concerning how to make and use the claimed invention. Therefore, it was not necessary to provide a full and detailed explanation where, as here, a POSITA would know how to implement the claim.

81. As for Dr. Jacobsen's assertion that there is no written description support for "the shared memory allocated to the [deinterleaver / interleaver] is used at the same time as the shared memory allocated to the [interleaver / deinterleaver]," I disagree. Jacobsen Report at ¶ 155. 2Wire actually took the opposite position in its claim construction briefing:

Defendants' proposed construction correctly reflects that the shared memory is read to and written from at the same time by the interleaver and the deinterleaver. Defendants' proposed construction is consistent with the specification, which discloses that "the transmitter and/or receiver latency paths of the transceiver can share an interleaver/deinterleaver memory and the shared memory can be allocated to the interleaver and/or deinterleaver of each latency path."

Parties' Joint Claim Construction Brief for the Family 3 Patents, D.I. No. 353, at p. 58. Additional disclosure that shows that the patent applicant had possession of this element of the claimed invention at the time the patent application was filed is found at, e.g., U.S. Patent 7,831,890<sup>1</sup> patent at, e.g., Fig. 1 (illustrating shared memory 120 that services at least two interleaving functions and two deinterleaving functions); 6:56-64 and 7:7-25 (explaining that "the transmitter portion and/or receiver portion latency paths would be reconfigured to utilize the shared memory" and describing simultaneous transmitting/encoding and decoding/receiving of the latency paths); 8:11-39 (describing simultaneous use of different portions of a shared memory for various applications).

82. Dr. Jacobsen also asserts that the Family 3 patents lack written description support "wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message." She does not provide any explanation of why this is so. In any event, I disagree. Disclosure that shows that the patent applicant had possession of this element of the claimed invention at the time the patent application was filed is found generally because the specification discloses the use of "shared memory" by an interleaver and a deinterleaver where the Court interpreted shared memory to mean "common memory used by at least two functions, where a portion of the memory can be used by either one of the functions." CC Memo at p. 5. A POSITA would understand from the disclosure

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<sup>1</sup> The '890 patent is the original, non-provisional application in the chain with the asserted Family 3 patents.

of shared memory that the portion of shared memory that is allocated to an interleaver would not be used at the same time by a deinterleaver but, instead, could be used at alternative times depending on the allocation in effect at the time.

83. I reserve the right to address any support or explanation Dr. Jacobsen's attempts to provide for her currently conclusory assertions regarding written description and enablement.

84. Based on the foregoing, it is my opinion that the claim 1 of the '048 patent, claim 5 of the '381 patent, and claim 13 of the '882 patent satisfy the written description and enablement requirements.

### **C. Certificate of Correction**

85. I disagree with Dr. Jacobsen's opinion that the "Certificate of Correction changed the scope and meaning of the '381 and '882 patent." Jacobsen Report at ¶ 160. The certificate of correction was properly issued by the patent office to correct obvious typographical errors. Claim 5 of the '381 patent as corrected provides in relevant part:

5. A non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver comprising:

allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission reception at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message;

allocating, in the transceiver, a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes received transmitted at a second data rate;

86. I have reviewed the specification and it is my opinion that based on the specification, it is clear that the errors were clerical or typographical. Specifically, FIG. 1 of the specification depicts an interleaver as being associated with transmitting and the deinterleaver as being associated with reception. On the other hand, the specification is not consistent with Dr. Jacobsen's hypothetical device that deinterleaves RS coded data bytes before transmitting them and receives RS coded data bytes before interleaving them. Indeed, the best Dr. Jacobsen can say is that the Family 3 patents "do not appear to foreclose either of these possibilities."

87. Dr. Jacobsen's suggests that the statement in the specification that "the invention can be applied to any transceiver having any number of latency paths" somehow precludes the correction. I disagree. That statement merely means that a transmitter of a transceiver can have any number of latency paths and the receiver of the same transceiver can have any number of latency paths. For example, a CO transmitter could have one or two downstream latency paths to the CPE and one or two upstream latency paths from the CPE.

88. Dr. Jacobsen's assertion that "a person of ordinary skill in the art would [not] have considered the terms 'transmission' and 'received' in claim 5 of the '381 patent and claim 13 of the '882 patent to be typographical errors" is not credible, especially so in light of the statements made elsewhere in the Jacobsen Report. For example, at ¶ 55 of the Jacobsen Report, Dr. Jacobsen concedes that "[t]o apply interleaving, the transmitter shuffles consecutive bytes of the data stream in a known and systematic way before transmitting them . . . ." See also, Jacobsen Report at ¶ 60 (".

. . . transmitter interleaves the bytes prior to transmission.”). Thus, Dr. Jacobsen recognizes that bytes are interleaved prior to being “transmitted.” Dr. Jacobsen also admits that “the receiver . . . can reverse the interleaving process by collecting all of the interleaving data elements and using a complementary deinterleaving process.” Jacobsen Report at ¶ 58. Thus, Dr. Jacobsen recognizes that bytes are deinterleaved after “reception.”

89. Accordingly, her assertion that the errors were not typographical (or that they would not have been recognized as typographical) is meritless.

## **VI. ANALYSIS OF THE CITED REFERENCES**

### **A. The Asserted Claims Are Not Obvious Over LB-031**

90. It is my opinion and conclusion that LB-031 alone or in combination with other cited references fails to disclose or suggest each element of the Asserted Claims, and hence fails to render the Asserted Claims anticipated or obvious as described in detail, below.

91. It is also my opinion that regardless of the disclosure of LB-031 and the other cited references, a person of ordinary skill in the art would not be motivated to combine the teachings of LB-031 with the teachings of the other cited references at least for the reasons described in Section VI.A.2.a, *infra*.

#### **1. Overview of LB-031**

92. LB-031 focuses on defining an interleaver delay in units of time to allow reduced interleaver complexity at lower data rates. *See* LB-031 at 3 (2WIRE00030959) (“Therefore, it seems prudent to define the interleaver complexity requirements in a



way that will allow those who want to deploy VDSL2 at lower speeds to do so at a reduced complexity with respect to higher speed implementations. The way to do this and to guarantee some minimum level of performance is to specify the interleaver complexity in terms of the delay in time.”).

93. LB-031 notes that the delay in time is proportional to the interleaver depth and to the codeword size and inversely proportional to the data rate. *Id.*

94. LB-031 describes memory requirements for an “interleaver/deinterleaver pair.” *See, e.g.,* LB-031 at 2 (2WIRE00030958) (“The smallest amount of memory required to build an interleaver/deinterleaver pair is equal to the total delay of the interleaver/deinterleaver. Typically, for memory optimized interleavers, the interleaver and deinterleaver memory size is nearly the same.”). *See also* § VI.A.2, *infra*. The interleaver of this “pair” is located in the transmitter lineup of one transceiver, while the deinterleaver of the “pair” is located in the receiver lineup of the other transceiver. The “pair” are associated with a single latency path and direction, i.e., a single path in the upstream direction or a single path in the downstream direction.

95. While LB-031 acknowledges that “[t]he size of the interleaver memory will be a major source of complexity in VDSL2,” it does not describe the combined memory requirements of an interleaver associated with one direction (e.g., upstream) and deinterleaver associated with the other direction (e.g., downstream) within a single transceiver. Nor does it describe sharing a memory between an interleaver and deinterleaver in a single transceiver as called for by the Asserted Claims of the Family 3 Patents and as described in more detail in VI.A.2, *infra*, and IV.A-IV.B, *supra*. Instead,

LB-031 focuses on selecting an amount of interleaver or deinterleaver memory for a single direction (i.e., by comparing capabilities of the transmitter on one end of a communication channel with the capabilities of the receiver on the other end). *See, e.g.*, LB-031 at 3 (2WIRE00030959). The relevant portion of LB-031 is quoted below:

For interoperability reasons, the VTU-O and VTU-R must exchange the interleaver delay in terms of octets. The requirement is that the interleaver delay in octets be sufficient to satisfy the smallest maximum delay even at the highest supported data rate. If a VDSL2 implementation supports a larger interleaver memory than is required, it should be free to specify the larger value. The VTU-O and VTU-R would then select the smaller of the transmitter and receiver capabilities, in each direction, as the end-to-end capabilities.

*Id.*

96. Contrary to Dr. Jacobsen's opinion, there is nothing in LB-031 that would suggest to a POSITA that a memory is being shared, or should be shared, between an interleaver and a deinterleaver in a single transceiver.

97. At least for these reasons, and for the reasons described in detail below, it is my opinion and conclusion that LB-031 fails to disclose or suggest all element of the Asserted Claims, and hence fails to render the Asserted Claims obvious.

## **2. LB-031 Does Not Render Claim 1 of the '048 Patent Obvious**

98. It is my opinion and conclusion that LB-031 alone or in combination with other cited references fails to disclose or suggest each element of claim 1 of the '048 patent, and hence fails to render the Asserted Claims anticipated or obvious as described in detail, below.

**a. LB-031 does not disclose a system that allocates shared memory.**

99. Contrary to Dr. Jacobsen's assertion, the LB-031 reference does not disclose a system that allocates shared memory. *See* Jacobsen Report at ¶¶ 179-181. Dr. Jacobsen has not pointed to any portion of LB-031 that states, or that would have disclosed to a POSITA that a transceiver implementing the LB-031 reference allocates shared memory.

100. Dr. Jacobsen points to Eq. 1 and Eq. 5, and corresponding descriptions in the LB-031 reference to assert that a POSITA "would have understood this example to teach allocating memory for interleaving and deinterleaving." *See* Jacobsen Report at ¶ 180. As an initial matter, this statement is vague because it is not clear whether it is intended to describe the memory of a single transceiver or, on the other hand, the separate memories of a respective interleaver in one transceiver and corresponding deinterleaver in a second transceiver. To the extent she intends the latter, such teaching is not relevant to any asserted claim of the Family 3 patents because the claims are directed to allocating a shared memory between and interleaver and deinterleaver within a single transceiver. To the extent she intends the former, her statement is incorrect.

101. The disclosure of LB-031 Dr. Jacobsen relies on for purportedly disclosing allocating a shared memory is the passage on page 4 of LB-031, which states "[i]f the minimum interleaver delay requirement were 5.23 ms, then, from equation (5) and equation (1), this transceiver must support a delay of at least 29092 octets which corresponds to having an interleaver memory of at least 14546 octets according to

equation (2).” *See* Jacobsen Report at ¶ 180. This discussion in LB-031, however, has nothing to do with sharing memory or allocating a shared memory. Rather, it is describing the memory requirements for an interleaver in one transceiver and the corresponding memory requirements for a deinterleaver in a second transceiver at the other end of the communication channel. As the reference discloses, for an end-to-end delay of 29092 octets, the interleaver memory in one transceiver would have to be 14546 octets (i.e., bytes). The deinterleaver memory for the corresponding deinterleaver in the transceiver at the other end of the communication channel would also be 14546. The memory requirements are the same for the interleaver and corresponding deinterleaver because the deinterleaver will deinterleave the interleaved byte stream that was interleaved by the interleaver.

102. Yet, Dr. Jacobsen omits the fact that the equations of LB-031 are to be used to separately characterize the delay and memory requirements for a single latency path/direction. *See id.* These equations do not characterize the combined memory requirements for a single transceiver that requires memory for an interleaver for a first latency path/direction and a deinterleaver for a second latency path/direction. The equations are not concerned with the combined memory limit of any single transceiver or with sharing or allocating that combined limit between an interleaver and a deinterleaver. Rather, LB-031 is perfectly consistent with the practice at the time of using a dedicated, fixed-size interleaver memory and a separate, dedicated, fixed-size deinterleaver memory within a transceiver. As explained in Section VI.A.1, *supra*, LB-

031 falls within the category of dedicated interleaver and deinterleaver memory implementations. *See also* § IV.A, *supra*.

103. I note that Dr. Jacobsen understands that DSL transceivers generally transmit/interleave in one direction while they are receiving/deinterleaving in the other direction.<sup>2</sup> *See, e.g.*, Jacobsen Report at ¶ 207 (“VDSL transceivers transmit and receive data at the same time (i.e., VTU-O transmits data downstream and receives data upstream at the same time, and the VTU-R transmits data upstream and receives data downstream at the same time.”). She ignores or attempts to confuse this fundamental detail, however, when comparing the preamble (and notably all the other elements of the claims, except the last) to the LB-031 reference.

104. The claim construction of the term “shared memory” further supports the fact that LB-031 does not disclose shared memory, or allocating shared and consequently does not disclose a system for allocating shared memory. Specifically, the Court construed “shared memory” to mean “common memory used by at least two functions, where a portion of the memory can be used by either one of the functions.” Claim Construction Order for Family 3 Patents (December 28, 2017) (“CC Order”) at p. 2.

105. The second portion of the construction (i.e., that “a portion of [the shared] memory can be used by either function”) means that the shared memory is a memory of a single transceiver. For example, the two functions in the context of the claim (and in

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<sup>2</sup> This is not the case, however, when the transceiver provides only half-duplex communications, i.e., the transceiver transmits but does not receive at some times and receives but does not transmit at other times.

the context of the asserted claims of the Family 3 patents generally) are interleaving and deinterleaving. The concept of use of a portion of memory by either one function or the other function has been described in Section VI.A.5.b, *infra*. See also § IV.A, *supra*. As discussed in connection with the '473 patent, *infra*, the interleaving function and corresponding deinterleaving function of the other transceiver specifically discussed in LB-031 use entirely different memories in different transceivers. No portion of memory within a single transceiver is disclosed by LB-031 to be used by an interleaver at one time or a deinterleaver at another time. See § VI.A.5.b.

106. Second, Dr. Jacobsen inappropriately extends the actual disclosure and teachings of the LB-031 reference by making an inherency argument that contradicts her other arguments. See Jacobsen Report at ¶ 181. Dr. Jacobsen asserts that “one of ordinary skill in the art would have understood from the disclosures of LB-031 that the allocated memory can be a shared memory.” See *id.* This is incorrect. First, Dr. Jacobsen has not identified any disclosure in LB-031 that requires that a shared memory is used or that any portion of memory within a single transceiver can be used by the interleaver or the deinterleaver. Rather, again, LB-031 is perfectly consistent with the practice of its time, which was to use a dedicated, fixed-size interleaver memory and a separate, dedicated, fixed-size deinterleaver memory in a transceiver. See § VI.A.5.a, *infra*; see also §§ IV.A, and IV.B, *supra*. Thus, no portion of a memory can be used by either an interleaver or a deinterleaver (i.e., no portion of the dedicated interleaver memory will ever be used by the deinterleaver and no portion of the dedicated deinterleaver memory will ever be used by the interleaver.).

107. Further, Dr. Jacobsen recognizes that LB-031 explains that “[t]he size of the interleaver memory will be a major source of complexity in VDSL2.” See Jacobsen Report at ¶ 181 (citing LB-031 at 3.). This statement does not state or suggest that size or complexity can be reduced by sharing memory. Rather, this statement would discourage a POSITA from attempting to add further complexity to interleaver memory in VDSL2, such as by proposing a memory sharing scheme. See also, e.g., LB-031 at 3 (2WIRE00030959) (“Therefore, it seems prudent to define interleaver complexity requirement in a way that will allow those who want to deploy VDSL2 at lower speeds to do so that at a reduced complexity with respect to higher speed implementations.”).

108. Therefore, I do not agree that a POSITA would understand “from the disclosures of LB-031 that the allocated memory can be a shared memory,” as Dr. Jacobsen incorrectly asserts, because a shared memory implementation would increase and not decrease the complexity of the implementation proposed by the LB-031 reference. See Jacobsen Report at ¶ 181.

109. I also disagree with Dr. Jacobsen’s assertion that “it was well known by the priority date of the Family 3 patents that an interleaver and deinterleaver memory could share a memory.” See Jacobsen Report at ¶ 181. I address this in Sections IV.A, IV.B, and IV.C, *supra*. Additionally, and *arguendo*, even if any of the string-cited references in paragraph 182 of the Jacobsen Report disclose a system for sharing memory as construed by the Court (which they do not), Dr. Jacobsen fails to explain why a POSITA would look to any of these references to increase complexity of the implementation of the LB-031 disclosure. Rather, as I have explained immediately

above, a POSITA would be discouraged from adding complexity to the memory requirement specifying scheme of LB-031. Consequently, there would be no motivation to combine any of the references cited in Paragraphs 182 of the Jacobsen Report with LB-031. And Dr. Jacobsen supplies none.

110. Because the LB-031 reference does not disclose, teach, or suggest a system that allocates sheared memory, it does not render claim 1 of the '048 patent anticipated or obvious. Also, because a person of ordinary skill in the art would not have understood from the teaching of the LB-031 reference to require a use of a shared memory, the LB-031 reference does not render claim 1 of the '048 patent anticipated or obvious. Finally, because a person of the ordinary skill in the art would not be motivated to combine the teaching of the LB-031 reference with the teaching of any other references cited by Dr. Jacobsen, and in fact, would be discouraged to do so, the LB-031 reference in combination with any of those references or in combination with the knowledge of one of ordinary skill in the art at the time of the invention of the Family 3 patents, does not render claim 1 of the '048 patent obvious.

**b. LB-031 does not disclose determining an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within the shared memory.**

111. LB-031 does not disclose this claim element.

112. Dr. Jacobsen ignores the requirement of this claim element that calls for a “shared memory” and instead irrelevantly quotes the portions of LB-031 describing the memory requirements for an interleaver in one transceiver and a corresponding memory requirement for a deinterleaver in another transceiver (and not an



implementation in a single transceiver with a shared memory). *See* Jacobsen Report at ¶ 192.

113. At least because LB-031 is not directed to allocating shared memory described in § VI.A.1 and § VI.A.2.a, *supra*, the LB-031 reference does not disclose, teach, or suggest this claim element. *See* § VI.A.5.a, *infra*; *see also* §§ IV.A, and IV.B, *supra*.

114. Because LB-031 does not disclose, teach, or suggest determining an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within the shared memory, it does not render claim 1 of the '048 Patent obvious.

**c. LB-031 does not disclose allocating a first number of bytes of the shared memory to the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate.**

115. LB-031 does not disclose, teach, or suggest this claim element.

116. As with the previous claim element, Dr. Jacobsen yet again ignores the requirement of this claim element that calls for a “shared memory.” *See* Jacobsen Report at ¶¶ 194-195. The claim overall, and also this element in particular, calls for allocating bytes of a shared memory. LB-031 lacks disclosure of a shared memory as construed by the Court. *See* §§ VI.A.1, VI.A.2.a. *See also* § VI.A.5.a, *infra*; *see also* §§ IV.A, and IV.B, *supra*.

117. Dr. Jacobsen relies on a passage from LB-031 describing an exchange between a VTU-O and VTU-R of capabilities (i.e., a VTU-R and VTU-O will select “the

smaller of the transceivers and receiver capabilities in each direction.”). But the implementation details are all described in the context of the interleaver/deinterleaver pair for a single direction, e.g., interleaver capabilities of the VTU-O and deinterleaver capabilities of the VTU-R for the downstream direction. While the exchange of capabilities allows the transceivers to use only up to the amount of memory that is the lesser of the amount of interleaver memory in the VTU-O or the amount of deinterleaver memory in the VTU-R, there is no contemplation or discussion of sharing memory within a single transceiver depending on the exchanged capabilities. Thus, Dr. Jacobsen’s conclusion that a “shared memory” is being allocated is not supported by the LB-031 reference. *See* Jacobsen Report at ¶ 194; *see also* LB-031 at 2 (2WIRE00030958). Again, as explained in §§ VI.A.1, VI.A.2.a, *supra*, the disclosure of the LB-031 reference is not directed to shared memory. *See also* § VI.A.5.a, *infra*; *see also* §§ IV.A, and IV.B, *supra*.

118. Because LB-031 does not disclose, teach, or suggest allocating a first number of bytes of the shared memory to the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, it does not render claim 1 of the ‘048 Patent obvious.

**d. LB-031 does not disclose wherein the allocated memory for the interleaver does not exceed the maximum number of bytes in the message.**

119. LB-031 does not disclose this limitation at least because, as I explain in Section VI.A.2.a, *supra*, it does not disclose allocating memory to an interleaver (or a deinterleaver.)

120. Because LB-031 does not disclose, teach, or suggest transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver, it does not render claim 1 of the '048 patent obvious.

**e. LB-031 does not disclose allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received a second data rate.**

121. LB-031 does not disclose, teach, or suggest this claim element.

122. Dr. Jacobsen makes the same arguments for this claim element as for the element discussed in Section VI.A.2.c, *supra*, all of which have been addressed in the same section, *supra* and are incorporated by reference with respect to this claim element.

123. As with the previous element, LB-031 lacks disclosure of shared memory as construed by the Court. Therefore, LB-031 cannot disclose or suggest this claim element. *See* §§ VI.A.1, VI.A.2.a; *see also* § VI.A.5.a, *infra* and §§ IV.A and IV.B, *supra*.

124. Again, the implementation details of LB-031 are all described in the context of the interleaver/deinterleaver pair for a single direction, e.g., interleaver capabilities of the VTU-O and deinterleaver capabilities of the VTU-R for the downstream direction. There is no disclosure or contemplation of sharing a memory within a single transceiver for an interleaver operating in a first direction and a deinterleaver operating in a second direction. Thus, even assuming, *arguendo*, that LB-031 discloses “allocating a first number of bytes of” a non-shared memory “to the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate,” there is no disclosure or contemplation of “allocating

a second number of bytes of” the same memory “to a deinterleaver to deinterleave a second plurality of RS coded data bytes received a second data rate.” The deinterleaving of “a second plurality of RS coded data bytes received at a second data rate” recited in the claim is necessarily referring to communications made in the other direction. LB-031 does not describe sharing memory between an interleaver for one direction and a deinterleaver for the other direction.

125. Because LB-031 does not disclose, teach, or suggest allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received a second data rate, it does not render claim 1 of the ‘048 Patent obvious.

- f. **LB-031 does not disclose interleaving the first plurality of RS coded data bytes within the shared memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver.**

126. LB-031 does not disclose, teach, or suggest this claim element.

127. Dr. Jacobsen makes the same arguments for this claim element as for the previous claim element, all of which have been addressed in § VI.A.2.c, *supra* and are incorporated by reference with respect to this claim element.

128. As with the previous elements, LB-031 lacks disclosure of shared memory as construed by the Court. Again, LB-031 is consistent with the practice at that time of using a dedicated interleaver memory and a separate deinterleaver memory. Thus, LB-031 does not describe interleaving and deinterleaving within a shared memory as

required by this claim element. *See* §§ VI.A.1, VI.A.2.a; *see also* § VI.A.5.a, *infra* and §§ IV.A and IV.B, *supra*.

129. Dr. Jacobsen again ignores the requirement that the memory be shared within a single transceiver as required by this claim as further supported by the Court's construction of the term. Notably, Dr. Jacobsen does not cite to a specific portion of LB-031 reference to support its conclusion that a single transceiver would interleave and deinterleave within a shared memory. *See* Jacobsen Report at ¶ 205. Instead, Dr. Jacobsen repeats the claim element and jumps to an unsupported conclusion that it is met by LB-031.

130. Because LB-031 does not disclose, teach, or suggest interleaving the first plurality of RS coded data bytes within the shared memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver, it does not render claim 1 of the '048 Patent obvious.

**g. LB-031 does not disclose wherein the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver.**

131. LB-031 does not disclose, teach, or suggest this claim element.

132. As discussed in Sections VI.A.1, VI.A.2.a, VI.A.3.c, VI.A.2.e, *supra*, and in Section VI.A.5.a, *infra*, LB-031 does not disclose allocating shared memory in a single transceiver. At least because of the lack of disclosure directed to shared memory and to allocation of such memory, LB-031 does not disclose, teach, or suggest this claim element.

133. Dr. Jacobsen argues that because a transceiver can transmit and receive at the same time, this element is met. *See* Jacobsen Report at ¶ 207. When making this conclusory argument, Dr. Jacobsen overlooks the fact that the allocated memory refers to memory that can be allocated to an interleaver or a deinterleaver of a single transceiver as discussed in Sections VI.A.1, VI.A.2.a, VI.A.3.b, VI.A.2.e, *supra*. *See also* § VI.A.5.a.

134. At least because LB-031 does not disclose the claimed allocation of memory as discussed in, for example, Sections VI.A.3.c, VI.A.2.e, *supra*, LB-031 cannot disclose or suggest this element of claim 1 of the '048 patent.

135. Because LB-031 does not disclose, teach, or suggest wherein the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver, it does not render claim 1 of the '048 Patent obvious.

### 3. LB-031 Does Not Render Claim 5 of the '381 Patent Obvious

136. It is my opinion and conclusion that LB-031 alone or in combination with other cited references fails to disclose or suggest each element of claim 5 of the '381 patent, and hence fails to render the Asserted Claims anticipated or obvious as described in detail, below.

- a. **LB-031 does not disclose a non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver.**

137. LB-031 describes a prior art system that is not related to sharing memory in a transceiver. *See generally* § VI.A.1, *supra*.

138. As described in Section VI.A.2.a, LB-031 does not include any disclosure directed to allocating shared memory in a transceiver. Consequently, for the same reasons as described with respect to claim 1 of the '048 patent, LB-031 fails to disclose this element of claim 5 of the '381 patent.

139. Additionally, Dr. Jacobsen does not identify any portions of LB-031 that disclose a non-transitory computer-readable information storage media having stored thereon instruction that are executed by a processor. *See* Jacobsen Report at ¶ 210. Instead, Dr. Jacobsen without any support simply draws an inference that “[o]ne of ordinary skill in the art would have understood that a source code and instructions for such transceivers could be stored on computer-readable information storage media, and could be executed by a processor.” *See id.*

140. First of all, Dr. Jacobsen’s conclusion is wrong on its face. Source code (or object code) cannot be executed by a processor. A POSITA would understand that source code (or object code) is a term of art referring to uncompiled and non-executable human readable code.

141. Even ignoring the fact that Dr. Jacobsen’s conclusion is wrong on its face, Dr. Jacobsen did not show that any element of claim 5 of the '381 patent is performed by executing instructions stored on a non-transitory computer-readable information media. A POSITA would understand that it is possible that one or more of the claimed functions could be implemented in hardware, and therefore would not necessarily have to be carried out through an execution of instructions stored on a non-transitory computer-readable media. Dr. Jacobsen did not even attempt to show one way or

another with which of these possibilities LB-031 would be concerned with respect to each claimed function.

142. It is my opinion that LB-031 does not disclose, teach, or suggest this claim element of claim 5 of the '381 patent and therefore fails to render claim 5 of the '381 Patent obvious.

- b. LB-031 does not disclose determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory.**

143. LB-031 does not disclose, teach, or suggest this claim element.

144. Dr. Jacobsen incorporates her arguments from Section IX.A.3.d of the Jacobsen Report, which have been addressed *supra* in Section VI.A.2.b with respect to claim 1 of the '048 patent.

145. Because LB-031 does not disclose, teach, or suggest determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory, it does not render claim 5 of the '381 Patent obvious.

- c. LB-031 does not disclose allocating a first number of bytes of the shared memory to the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate.**

146. LB-031 does not disclose allocating, at the transceiver, a first number of bytes of shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate.

147. LB-031 does not disclose, teach, or suggest this claim element.



148. Dr. Jacobsen incorporates her arguments from Section IX.A.3.e of the Jacobsen Report, which have been addressed *supra* in Section VI.A.2.c with respect to claim 1 of the '048 patent and with respect to an interleaver.

149. Additionally, Dr. Jacobsen incorporates her arguments from Section IX.A.3.g of the Jacobsen Report, which have been addressed *supra* in Section VI.A.2.e with respect to claim 1 of the '048 patent and with respect to a deinterleaver.

150. Because LB-031 does not disclose, teach, or suggest allocating, at the transceiver, a first number of bytes of shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, it does not render claim 5 of the '381 Patent obvious.

**d. LB-031 does not disclose wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes in the message.**

151. LB-031 does not disclose this limitation at least because, as I explain in Section VI.A.2.a, *supra*, it does not disclose allocating memory to an interleaver (or a deinterleaver.)

152. Dr. Jacobsen incorporates her arguments from Section IX.A.3.f of the Jacobsen Report, which have been addressed *supra* in Section VI.A.2.d with respect to claim 1 of the '048 patent. Although, claim 1 of the '048 is directed to “allocated memory for the interleaver,” my arguments hold true for “allocated memory for the deinterleaver,” as recited in claim 5 of the '381 patent, at least because LB-031d does not disclose a system for allocating memory to an interleaver or to a deinterleaver. *See, e.g.*, § VI.A.2.a.

153. Because LB-031 does not disclose, teach, or suggest transmitting or receiving, by the transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver, it does not render claim 5 of the '381 patent obvious.

- e. **LB-031 does not disclose allocating, at the transceiver, a second number of bytes of shared memory to an interleaver to interleave a second plurality of Reed Solomon (RS) coded data bytes for transmission at a second data rate.**

154. LB-031 does not disclose, teach, or suggest this claim element.

155. Dr. Jacobsen incorporates her arguments from Section IX.A.3.e of the Jacobsen Report, which have been addressed *supra* in Section VI.A.2.c with respect to claim 1 of the '048 patent and with respect to an interleaver.

156. Additionally, Dr. Jacobsen incorporates her arguments from Section IX.A.3.g of the Jacobsen Report, which have been addressed *supra* in Section VI.A.2.e with respect to claim 1 of the '048 patent and with respect to a deinterleaver.

157. Because LB-031 does not disclose, teach, or suggest allocating, at the transceiver, a second number of bytes of shared memory to an interleaver to interleave a second plurality of Reed Solomon (RS) coded data bytes for transmission at a second data rate, it does not render claim 5 of the '381 Patent obvious.

- f. **LB-031 does not disclose deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver.**

158. LB-031 does not disclose, teach, or suggest this claim element.

159. Dr. Jacobsen incorporates her arguments from Section IX.A.3.h of the Jacobsen Report, which have been addressed *supra* in Section VI.A.2.f with respect to claim 1 of the '048 patent. The difference in wording of this claim element as compared with the corresponding claim element of claim 1 of the '048 is of no consequence to my arguments.

160. Because LB-031 does not disclose, teach, or suggest deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver., it does not render claim 5 of the '381 Patent obvious.

**g. LB-031 does not disclose wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver.**

161. LB-031 does not disclose, teach, or suggest this claim element.

162. Dr. Jacobsen incorporates her arguments from Section IX.A.3.i of the Jacobsen Report, which have been addressed *supra* in Section VI.A.3.g with respect to claim 1 of the '048 patent. The difference in wording of this claim element as compared with the corresponding claim element of claim 1 of the '048 is of no consequence to my arguments.

163. Because LB-031 does not disclose, teach, or suggest deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the

shared memory allocated to the interleaver., it does not render claim 5 of the '381 Patent obvious.

**4. LB-031 Does Not Render Claim 13 of the '882 Patent Obvious**

164. It is my opinion and conclusion that LB-031 alone or in combination with other cited references fails to disclose or suggest each element of claim 13 of the '882 patent, and hence fails to render the Asserted Claims anticipated or obvious as described in detail, below.

**a. LB-031 does not disclose a system that allocates shared memory.**

165. LB-031 does not disclose, teach, or suggest this claim element of claim 13 of the '882 Patent for the same reason as discussed with respect to the same claim element of claim 1 of the '048 Patent. *See* § VI.A.2.a.

**b. LB-031 does not disclose other elements of this claim.**

166. Dr. Jacobsen adopts wholesale her arguments with respect to claim 5 of the of the '381 patent (elements 5[b] – 5[h]) as her argument with respect to claim 13 of the '882 patent (elements 13[c] through 13[i], respectively). *See* Jacobsen Report at ¶ 232.

167. Accordingly, I hereby incorporate my arguments with respect to claim elements of claim 5 of the '381 patent, and also claim 1 of the '048 Patent as rebuttal argument for the respective claim elements of claim 13 of the '882 patent.

168. Specifically, using the claim element numbering from Dr. Jacobsen Report (*see* Appendix C to Jacobsen Report), I hereby incorporate herein the following sections of this report:

- with respect to element 13[d], I incorporate §§ VI.A.2.b, VI.A.3.b, *supra*;

- with respect to element 13[e], I incorporate §§ VI.A.2.c, VI.A.2.e, VI.A.3.c, *supra*;
- with respect to element 13[f], I incorporate §§ VI.A.2.d, VI.A.3.d, *supra*;
- with respect to element 13[g], I incorporate §§ VI.A.2.c, VI.A.2.e, VI.A.3.e, *supra*;
- with respect to element 13[h], I incorporate §§ VI.A.2.f, VI.A.3.f, *supra*;
- with respect to element 13[i], I incorporate §§ VI.A.2.g, VI.A.3.g, *supra*.

169. LB-031 does not disclose, teach, or suggest the above claim elements of claim 13 of the '882 Patent for the same reason as discussed with respect to the substantially similar claim elements of claim 5 of the '381 Patent, and claim 1 of the '048 Patent.

#### **5. LB-031 Does Not Render Claim 19 of the '473 Patent Obvious**

170. It is my opinion and conclusion that LB-031 alone or in combination with other cited references fails to disclose or suggest each element of claim 19 of the '473 patent, and hence fails to render the Asserted Claims anticipated or obvious as described in detail, below.

- a. **LB-031 does not disclose a multicarrier transceiver being associated with a memory wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during initialization of the transceiver.**
  - i. **LB-031 does not disclose a multicarrier transceiver being associated with a memory wherein the memory is allocated between the interleaving function and the deinterleaving function.**

171. LB-031 does not disclose, teach, or suggest a multicarrier transceiver being associated with a memory wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during initialization of the transceiver. As discussed in the Overview of LB-031 Section, *supra*, and also in connection with claim 1 of the '048 patent, *supra*, LB-031 does not disclose allocating a memory between an interleaver function and a deinterleaver function in a single transceiver but instead discloses exchanging "capability" information specifying the size of a dedicated interleaver memory and the size of a separate, dedicated deinterleaver memory. *See* § VI.A.1; *see also* § VI.A.2.a.

172. No portion of any memory contemplated by LB-031 is used as interleaver memory at one point in time and deinterleaver memory at another point in time and, thus, LB-031 does not allocate memory *between* an interleaving function and a deinterleaving function. Rather, one of ordinary skill in the art would understand LB-031 in the context of a system in which the CO transceiver (VTU-O) has a dedicated amount of memory available to be used for downstream interleaving and a separate, dedicated amount of memory available to be used for upstream deinterleaving and the CPE transceiver (VTU-R) has a dedicated amount of memory available to be used for

downstream deinterleaving and a separate, dedicated amount of memory available to be used for upstream interleaving. In the VTU-O, no portion of the dedicated downstream interleaver memory can be allocated for upstream deinterleaving and, no portion of the upstream deinterleaver memory can be allocated for downstream interleaving. Likewise, in the VTU-R, no portion of the dedicated upstream interleaver memory can be allocated for downstream deinterleaving and, no portion of the downstream deinterleaver memory can be allocated for upstream interleaving.

173. Dr. Jacobsen describes the disclosure in LB-031 of transceivers exchanging capabilities, including specifying the amount of memory a transceiver has available for a particular latency path by exchanging the end-to-end interleaver delay on octets that it can support for that latency path. *See* Jacobsen Report at ¶¶ 242-244. She refers to the disclosure in LB-031 that “[i]f a VDSL2 implementation supports a larger interleaver memory than is required, it should be free to specify the larger value,” in which case “[t]he VTU-O and VTU-R would then select the smaller of the transmitter and receiver capabilities.” *See* Jacobsen Report at ¶ 243 (citing LB-031 at 3). But this is merely standard behavior for DSL transceivers at that time. Dr. Jacobsen does not point to any disclosure in LB-031 where memory is allocated between an interleaving function and a deinterleaving function in accordance with a message. Further explanation of the distinctions between LB-031 and claim 19 of the ‘473 patent is provided below.

- ii. **LB-031 does not disclose the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during initialization of the transceiver.**

174. Even assuming that the exchange of information described in LB-031 occurs during initialization and occurs through an exchange of messages, LB-031 would not disclose to a person of ordinary skill in the art a message that is used to perform the claimed allocation. In particular, LB-031 discloses that “[i]f a VDSL2 implementation supports a larger interleaver memory than is required, it should be free to specify the larger value,” and that in such a case “[t]he VTU-O and VTU-R would then select the smaller of the transmitter and receiver capabilities, in each direction, as the end-to-end capabilities.” LB-031 at 3. This disclosure would be understood by a POSITA as follows:

For determining capabilities applicable to the downstream (DS) direction (i.e., downstream latency path from VTU-O to VTU-R):

Step 1. The VTU-O sends a message to the VTU-R that includes the amount (in octets) of downstream interleaver delay that the VTU-O can support (“Message 1-DS”).

Step 2. The VTU-R sends a message to the VTU-O that includes the amount (in octets) of downstream deinterleaver delay that the VTU-R can support (“Message 2-DS”).

Step 3. For the downstream deinterleaver delay capabilities, the VTU-R would select the smaller of the downstream interleaver delay amount indicated in Message 1-DS and the downstream deinterleaver delay amount indicated in Message 2-DS.

Step 4. Separately, for the downstream interleaver delay capabilities, the VTU-O would select the smaller of the downstream interleaver delay amount indicated in Message 1-DS and the downstream deinterleaver delay amount indicated in Message 2-DS.



(Step 4 may not be necessary because it will ultimately be up to the VTU-R to determine the amount of delay actually implemented for the downstream path.)

For determining capabilities applicable to the upstream (US) direction (i.e., upstream latency path from VTU-R to VTU-O):

Step 1. The VTU-O sends a message to the VTU-R that includes the amount (in octets) of upstream deinterleaver delay that the VTU-O can support ("Message 1-US").

Step 2. The VTU-R sends a message to the VTU-O that includes the amount (in octets) of upstream interleaver delay that the VTU-R can support ("Message 2-US").

Step 3. For the upstream deinterleaver delay capabilities, the VTU-O would select the smaller of the upstream deinterleaver delay amount indicated in Message 1-US and the upstream interleaver delay amount indicated in Message 2-US.

Step 4. Separately, for the upstream interleaver delay capabilities, the VTU-R would select the smaller of the upstream deinterleaver delay amount indicated in Message 1-US and the upstream interleaver delay amount indicated in Message 2-US.

(Step 4 may not be necessary because it will ultimately be up to the VTU-O to determine the amount of delay actually implemented for the upstream path.)

175. In the examples above, a single message from the VTU-O to the VTU-R could include the Message 1-DS and Message 1-US capabilities information and a single message from the VTU-R to the VTU-O could include the Message 2-DS and Message 2-US capabilities information. But, again, even if a POSITA would understand there to be a message exchange such as the example described above, no portion of memory is allocated between the interleaving function and the deinterleaving function in accordance with a message.

176. Instead, LB-031 at most discloses that, for the downstream direction, a VTU-R with a larger dedicated deinterleaver memory than is required can determine

whether the VTU-O also supports a larger amount. But, if the VTU-O does not support a larger amount than is required, however, the extra deinterleaver memory of the VTU-R is simply not used. For example, it is not available to be used for the upstream interleaver function. The examples described below illustrate this concept.

177. Example 1. VTU-O (30,000 octets of dedicated downstream interleaver memory; 30,000 octets of dedicated upstream deinterleaver memory). VTU-R (40,000 octets of dedicated downstream deinterleaver memory; 20,000 octets of dedicated upstream interleaver memory).

Legend:



dedicated downstream memory (interleaver memory for VTU-O,  
deinterleaver memory for VTU-R)



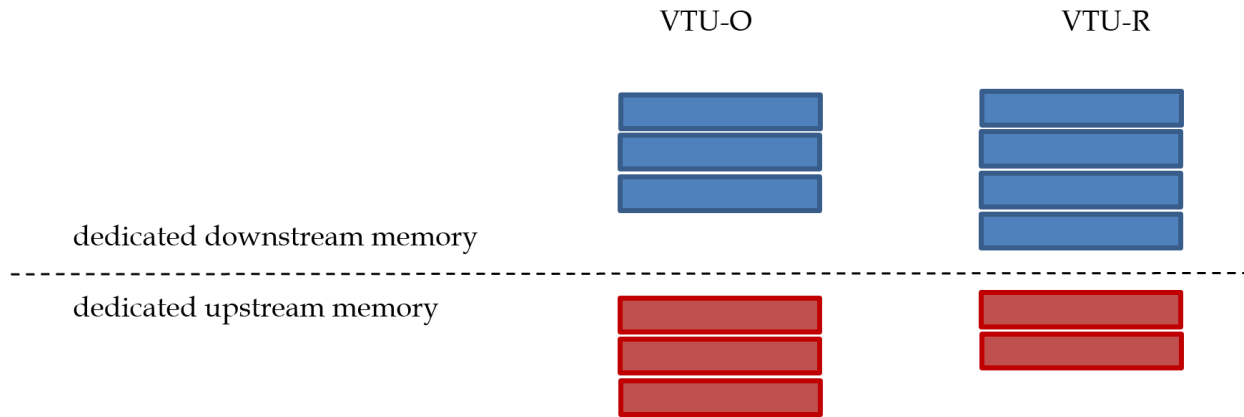
dedicated upstream memory (interleaver memory for VTU-R,  
deinterleaver memory for VTU-O)



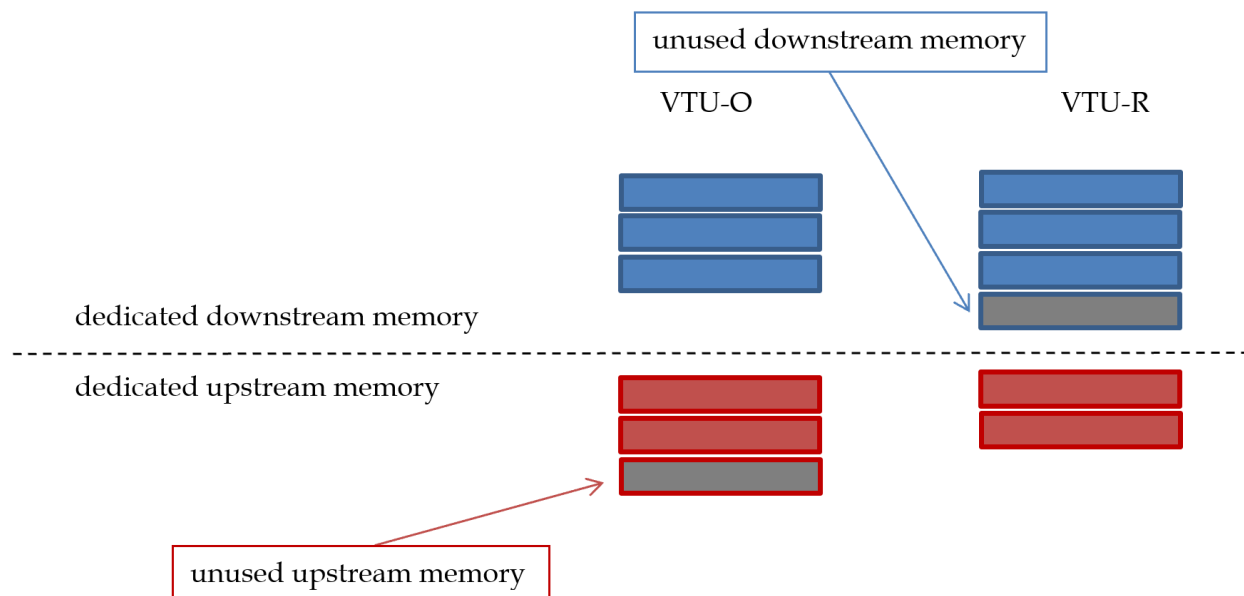
unused memory

Each rectangle represents 10,000 octets of memory.

178. Capabilities (maximum memory supported):



179. According to LB-031, each transmitter would exchange their memory capabilities in each direction and “then select the smaller of the transmitter and receiver capabilities, *in each direction*.” Consistent with the state of art of its time, LB-031 teaches that the smaller capability is selected. Because the smaller capability is selected, this results in a maximum possible memory allocation as shown below.



180. Because the smaller of the capabilities of the transmitter or receiver are selected in each direction in accordance with the express teaching of LB-031, unused

memory for one function in a transceiver cannot be used for another function, e.g., unused dedicated deinterleaver memory in the VTU-R cannot be used for the interleaving function. In the example above, 10,000 octets of deinterleaver memory within the VTU-R and 10,000 octets of deinterleaver memory in the VTU-O would never be used.

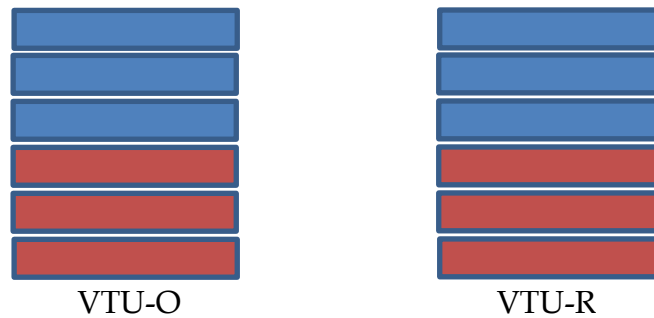
181. Under the LB-031 implementation even though the VTU-R learned about the VTU-O's capabilities downstream, it could not use 10,000 octets of its 40,000 octets of memory that was dedicated to the downstream deinterleaver. Likewise, even though the VTU-O learned about the VTU-R's capabilities upstream, it could not use 10,000 octets of its 30,000 octets of memory that was dedicated to the upstream deinterleaver.

182. In this example, if a service provider is providing a VDSL2 service that requires 30,000 octets of memory in each transceiver for the downstream service and 20,000 octets of memory in each transceiver for the upstream service, the transceivers would be able to provide that service. If, however, a service provider is providing a VDSL2 service that requires 30,000 octets of memory in each transceiver for the downstream service and 30,000 octets of memory in each transceiver for the upstream service, the transceivers would NOT be able to meet the requirements of the service.

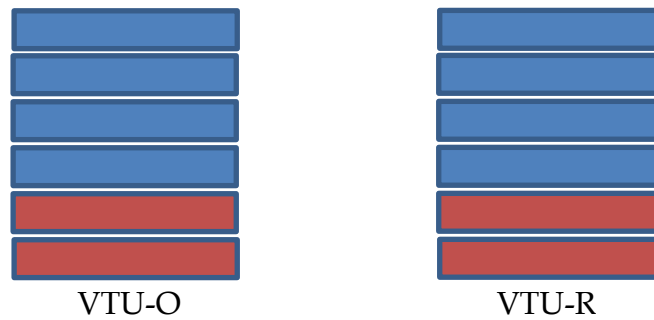
183. The above example can be contrasted with an example implementing the claimed allocation of memory between an interleaving function and a deinterleaving function according to the inventions of the Family 3 patents (Example 2, *infra*).

184. Example 2. Each transceiver supports a total of 60,000 octets of shared interleaver/deinterleaver memory. If the service provider desires to provide a VDSL2

service that requires 30,000 octets of memory in each transceiver for the downstream service and 30,000 octets of memory in each transceiver for the upstream service, the 60,000 octets of memory in each transceiver could be allocated between the interleaver and deinterleaver functions such that 30,000 octets in each transceiver are used for the downstream path and 30,000 octets are used for the upstream path as illustrated below.



185. On the other hand, if the service provider desires to provide a VDSL2 service that requires 40,000 octets of memory in each transceiver for the downstream service and 20,000 octets of memory in each transceiver for the upstream service, the 60,000 octets of memory in each transceiver could be allocated between the interleaver and deinterleaver functions such that 40,000 octets in each transceiver are used for the downstream path and 20,000 octets are used for the upstream path as illustrated below.



186. Therefore, unlike LB-031 where 10,000 octets of memory are unused and the service provider could not provide the service to the customer, when shared memory, which can be allocated between the interleaver function or deinterleaver function, is used, memory that would otherwise go unused can be allocated to one function or the other depending on messages that are, in part, dependent on the service requirements. As illustrated by these examples, the VTU-R is capable of allocating 10,000 octets of its memory to the upstream interleaving function at one time but allocating the same 10,000 octets of its memory to the downstream deinterleaving function at another time. This provides flexibility that enables the transceivers to meet different service requirements.

187. The claimed allocation of memory requires allocating the memory between an interleaving function and a deinterlacing function according to a message. LB-031 does not teach this claim element. Instead, as illustrated above, it allows a transceiver to determine how much of its pre-allocated downstream memory (i.e., interleaver memory in the VTU-O and deinterleaver memory in the VTU-R) and how

much of its pre-allocated upstream memory (i.e., deinterleaver memory in the VTU-O and interleaver memory in the VTU-R) can be used.

188. It is therefore my opinion that LB-031 does not disclose, teach, or suggest this claim element of claim 19 of the '473 Patent.

- b. LB-031 does not disclose a multicarrier transceiver being associated with a memory wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.**

189. LB-031 does not disclose, teach, or suggest these claim elements. As discussed in the Overview of LB-031 Section, and in the section immediately above, as well as in connection with claim 1 of the '048 patent, *supra*, LB-031 does not disclose any sharing of memory within a transceiver. *See* § VI.A.1; *see also* §§ VI.A.2.a, VI.A.5.a. Therefore, in a transceiver operating in accordance with LB-031, no portion of memory may be allocated to an interleaving function at one time or a deinterleaver function at another time depending on a message.

190. As discussed in paragraphs 177-182 above with respect to the Example 1, according to the teachings of LB-031, the dedicated interleaver memory may not at any particular time be allocated to the deinterleaver function and the dedicated deinterleaver memory cannot at any particular time be used for the interleaver function. The exchange of capabilities in LB-031, even assuming it is accomplished through messages exchanged during initialization, would not allow any portion of memory to be allocated to an interleaver function at one time or a deinterleaver function at another time depending on a message. Rather, any messages contemplated by LB-031 are used

only to select the smaller of the transmitter or receiver capabilities. This may result in portions of memory that are unused, as explained in paragraphs 179-182. It will not result in a portion of memory being used for one function or the other at a particular time depending on a message, as claimed.

191. Confusingly, Dr. Jacobsen argues that because a transceiver can transmit and receive at the same time, this element is met. *See* Jacobsen Report at ¶ 246. She does not explain how transmitting and receiving at the same time has anything to do with this claim element. In fact, the conclusion she draws from this is that LB-031 discloses that the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver. *Id.* The conclusion has no bearing on whether, and does not prove that, LB-031 discloses “at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.”

192. For the foregoing reasons, it is my opinion that LB-031 fails to disclose all elements of claim 19 of the ‘473 patent and therefore fails to render claim 19 of the ‘473 patent obvious.

**B. The Asserted Claims Are Not Obvious Over the Combination of LB-031 and Mazzoni**

193. It is my opinion and conclusion that Mazzoni alone or in combination with LB-031 fails to disclose or suggest each element of the Asserted Claims, and hence fails to render the Asserted Claims obvious as described in detail, below.



194. It is also my opinion that regardless of the disclosure of LB-031 and Mazzoni individually, a person of ordinary skill in the art would not be motivated to combine the teachings of LB-031 with the teachings of Mazzoni at least for the reasons described in Section VI.B.2, *infra*.

195. An overview of LB-031s has been provided in Section VI.A.1, *supra*.

### **1. Overview of Mazzoni**

196. The disclosure of Mazzoni is based on the premise that there is a finite group of data rate pairs, where each data rate pair comprise a predetermined upstream data rate and a predetermined downstream data rate). *See* Mazzoni at 1:65 – 2:2 (“The invention therefore provides a device for sending/receiving digital data that is capable of processing different bit rates from a group of predetermined bit rates (e.g., all the symmetrical or asymmetrical services offered by the VDSL communication system).”), 3:62 – 4:14 (describing six symmetrical and six asymmetrical data rate pairs). Mazzoni also refers to these data rate pairs as services, where a service utilizes one predetermined data rate in the upstream direction and another predetermined data rate in the downstream direction. *See id.* In a symmetric service, the upstream data rate is the same as the downstream data rate. *Id.* at 3:62 – 4:2. In an asymmetric service the two are different. *Id.* at 4:3-14. Mazzoni describes higher and lower bit rate examples of six possible symmetrical services:

The VDSL communication system enables the operator to provide symmetrical services, typically six symmetrical services S1-S6. That is, the information bit rates in the two transmission directions (i.e., from the operator to the user and from the user to the operator) are exactly the same. The service S1 with the lowest bit rate has a bit rate of 32x64 kbit/s,

for example, and the fastest symmetrical service S6 has a bit rate of 362x64 kbit/s.

*Id.* at 3:62 – 4:2. Mazzoni also describes example asymmetrical services with higher bit rates for the downstream direction:

With the VDSL system, the operator can also provide asymmetrical services A1-A6. These are services with different information bit rates in the user to operator direction (uplink direction) and in the operator to user direction (downlink direction). The first asymmetrical service A1 has a bit rate in the uplink direction of 32x64 kbit/s, for example, and a bit rate in the downlink direction of 100x64 kbit/s. The asymmetrical service having the highest global information bit rate (uplink bit rate+downlink bit rate) is the service A6. The bit rate of the service A6 in the uplink direction is equal to 32x64 kbit/s and in the downlink direction is equal to 832x64 kbit/s.

*Id.* at 4:3-14.

197. Mazzoni describes the assignment of interleaver memory and deinterleaver memory for each of the predefined data rate pairs (services). To accomplish this, Mazzoni proposes using predefined I and M parameter values for its interleaving means, and predefined I' and M' parameter values for deinterleaving means for each data rate pair (i.e., service).

198. This fixed correspondence of a data rate pair to predefined I and M parameter values (for interleaving) and predefined I' and M' parameter values (for deinterleaving) is explained by Mazzoni as follows:

These parameters define the sizes of the respective memory spaces assigned to the interleaving means and to the deinterleaving means. This is done according to the bit rate of the information sent by the terminal TO (parameters I and M) and the bit rate of the information received by the terminal TO (parameters I' and M').

*Id.* at 5:24-30.

199. “TO” in the above quoted language refers to a device at the “operator end.” *Id.* at 4:3:59-60. “TU” refers to a device at the “user end.” *Id.* Because the TO interleaves information to be transmitted downstream and deinterleaves information it receives in the upstream direction, the I and M interleaving parameters are associated with information sent by the TO, and similarly the I’ and M’ parameters are associated with information received by the TO. *See, e.g.,* Mazzoni at 5:27-30; Jacobsen Report at ¶¶ 96-100 (describing how the terms “interleaving” and “deinterleaving” are used in connection with the terms “upstream” and “downstream” communications in ADSL and VDSL).

200. Mazzoni explains that the predefined values of I and M specify the amount of predefined memory for the downstream interleaver of TO (and hence the downstream deinterleaver of TU) , and I’ and M’ specify the amount of predefined memory for an upstream deinterleaver of TO (and hence the downstream interleaver of TU), for a particular data rate pair (i.e., service). *See* Mazzoni at 6:38-43 (“More particularly, the size of the first memory space needed to implement triangular convolutional interleaving with I branches of  $i-1$  blocks of M bytes is equal to  $I \times (I-1) \times M / 2$ . Similarly, the size of the second memory space ESM2 required to support the uplink bit rate is equal to  $I' \times (I'-1) \times M' / 2$ .”); *see also id.* at 6:53-59 (“A table of values for the parameters I, M, I’ and M’ can therefore be stored in the coding/decoding stage. When the modem is installed at the end of the line, and depending on the service actually provided by the operator, the control means MCD may retrieve the corresponding values of I, M, I’ and M’ from the stored table.”); *id.* at 5:24-30. These

values are stored in a table within the modem and retrieved at the time of modem installation. *See* Mazzoni at 5:22-23, 6:51-55. Specifically, Mazzoni explains:

The above calculation of I, M, I' and M' for the asymmetrical service A6 can be applied in an analogous manner to the other services of the VDSL system. **A table of values for the parameters I, M, I' and M' can therefore be stored in the coding/decoding stage.** When the modem is installed at the end of the line, and depending on the service actually provided by the operator, **the control means MCD may retrieve the corresponding values of I, M, I' and M' from the stored table.** These values are delivered to the addressing means MAD1 and MAD2, the structure of which is described in more detail with reference to FIGS. 7 and 8.

Mazzoni at 6:51-61 (emphasis added).

201. As shown above in the quoted disclosure, the I, M, I', and M' parameter values are all predetermined for each data rate pair from a group of predefined data rate pairs and are stored in table. Mazzoni explains that at the time of the installation of the modem, the modem's memory is configured according to the I, M, I', and M' values retrieved from a table. Which values are retrieved depends on "the service actually provided by the operator," i.e., on the upstream and the downstream data rate pair configuration that is being provided by the service provided for the modem.

202. Dr. Jacobsen's description of Mazzoni is incomplete, and thus does not accurately characterize Mazzoni's teachings, because it overlooks Mazzoni's fundamental premise that a predefined data rate pair service and corresponding predefined I, M, I' and M' values will be fixed at the time of installation of a modem. For example, Dr. Jacobsen, citing Mazzoni at 6:19-50, states that the I, M, I', and M' parameters "can be determined from maximum and minimum memory size capacities that are easily calculable using downlink and uplink bit rates the number of bits

affected by noise, and RS error correction.” See Jacobsen Report at ¶ 256. Dr. Jacobsen does not explain further what this “determination” is, or when it occurs. See *id.* Yet, the portion of Mazzoni that she cites simply describes examples of how one can choose the predetermined values of the I, M, I’, and M’ parameters that are then stored in a table for retrieval at the time of installation of the modem. See Mazzoni at 6:19-50.

203. Also, because the data rate pair options are predetermined (and hence known in advance), and because there is a predetermined set of values for the I, M, I’ and M’ parameters for each predetermined data rate pair, there is no need for a device in Mazzoni to obtain any additional information from a device at the other end of the communication line in order to implement the memory assignment described by Mazzoni. Such an assignment is carried out in a sole reliance on the predetermined set of I, M, I’, and M’ parameters stored in a table and retrieved by the control means at the time of installation of the device. See Mazzoni at 6:53-59.

## 2. A Person of Ordinary Skill in the Art Would Not Combine the Teachings of LB-031 with the Teachings of Mazzoni

204. A person of ordinary skill in the art at the time of the invention of the Family 3 Patents would not look to the teachings of Mazzoni when implementing the teachings of LB-031, or *vice versa*. In fact, as explained below, the two references are so different that a person of ordinary skill in the art would be discouraged from looking to the teaching of the other reference.

205. An overview of LB-031 has been provided in Section VI.A.1, *supra*. The overview of Mazzoni has been provided in Section VI.B.1, *supra*.

206. Dr. Jacobsen asserts that “both Mazzoni and LB-031 disclose VDSL transceivers.” See Jacobsen Report at ¶ 346. This in and of itself, or in combination with any other argument made by Dr. Jacobsen in Section VIII.B.7 of the Jacobsen Report, is not sufficient to show that a person of ordinary skill in the art would have combined the teachings of the two references. At the time of the invention of the Family 3 Patents, the VDSL standard was still under development and there were likely hundreds, if not thousands, of references directed to possible implementation details of many and varied proposals for VDSL transceivers. One of skill in the art at the time would have understood that many of these references would be completely incompatible with one another and/or, if combined, would provide no useful benefit. Thus, that Mazzoni and LB-031 are purportedly both directed to different proposals for yet-to-be-defined VDSL transceivers, would not have made their combination obvious.

207. Dr. Jacobsen then states that “both Mazzoni and LB-031 are concerned with limiting the size of memory used for interleaving and deinterleaving.” See Jacobsen Report at ¶ 347. This in and of itself, or in combination with any other argument made by Dr. Jacobsen in Section VIII.B.7 of the Jacobsen Report, is again not sufficient to motivate a person of ordinary skill in the art to combine the teaching of the two references.

208. Also, this generalization is inaccurate. As explained in VI.A.1, *supra*, LB-031 is concerned with providing a solution that meets certain delay requirements specified in units of time, while allowing use of larger dedicated interleaver or deinterleaver memories if both transceivers support more than the minimum required

by a standard. There is no technique described in LB-031 for “limiting the size of memory used for interleaving and deinterleaving,” contrary to Dr. Jacobsen assertions. See § VI.A.1. Rather, as I explained above, LB-031 actually wastes memory by leaving portions of memory unused where one transceiver supports more memory for a given latency path than is supported by the other transceiver with which it is communicating. See § VI.A.1 and ¶¶ 176-187, *supra*. Because LB-031 wastes memory, a POSITA would be motivated **not** to use the teachings of LB-031 if they were concerned with reducing memory requirements.

209. Dr. Jacobsen states that: “[a] skilled artisan wishing to implement the VDSL transceiver of Mazzoni would have been motivated to include the initialization message of LB-031 so that the VTU-O and VTU-R of Mazzoni could choose values for the parameters  $I$ ,  $M$ ,  $I'$  and  $M'$  that would not exceed the size of the shared memory at the selected downstream and upstream bit rates.” See Jacobsen Report at ¶ 350. This is incorrect.

210. A POSITA would not look to add a message (from LB-031 or otherwise) to the system disclosed in Mazzoni, and in fact doing so would provide no useful benefit. This is because the system disclosed in Mazzoni relies on the use of a pre-populated table of  $I$ ,  $M$ ,  $I'$ , and  $M'$  parameter values, where each set of values corresponds to a respective one of a number of predetermined data rate service pairs. See Mazzoni at 5:22-23, 5:27-30, 6:51-55. There is no use for a message that specifies the maximum supported interleaver or deinterleaver memory size (assuming such a message is even disclosed per LB-031) because all data rate pairs and their corresponding  $I$ ,  $M$ ,  $I'$ , and  $M'$

values that need to be supported are accounted for. Mazzoni contemplates TO and TU transceiver pairs that will both be preconfigured at the time of installation with the same predetermined parameters selected from a limited number of possibilities. Thus, exchanging messages describing the capabilities of the transceivers would be redundant and serve no useful purpose.

211. An additional reason why LB-031's exchange of maximum supported memory sizes would not be recognized as beneficial to Mazzoni is that it is incompatible. Take an example where we assume that, per LB-031, the VTU-R (i.e., TU of Mazzoni) transmits to the VTU-O (i.e., TO of Mazzoni) a message that specifies the maximum downstream deinterleaver memory size that it supports and the maximum upstream interleaver memory size that it supports. Using the predefined services described in Mazzoni, i.e., S1-S6 and A1-A6 (*see* Mazzoni at 3:62 – 4:14), the maximum downstream deinterleaver memory that Mazzoni is capable of supporting is determined by reference to the A6 service and the maximum upstream interleaver memory that Mazzoni is capable of supporting is determined by reference to the S6 service. The A6 service provides a downstream bit rate of 832x64 kbit/s and requires 24,960 bytes of deinterleaver memory. *See id.* at 6:11-30 (describing calculation of required deinterleaver memory size). The S6 service provides an upstream bit rate of 362x64 kbit/s. Per the calculations described at 6:11-30 of Mazzoni, the S6 service requires that the VTU-R be capable of supporting a maximum upstream interleaver memory of 10,860 bytes. If the Mazzoni VTU-O received a message indicating that the VTU-R supported a maximum downstream deinterleaver memory of 24,960 bytes and a



maximum upstream interleaver memory of 10,860 bytes, this information would be useless to the VTU-O. First, it already has the information necessary to support the service for which both transceivers have been preconfigured at the time of installation. Second, neither the VTU-O or VTU-R would actually be capable of simultaneously supporting both maximum interleaver and deinterleaver sizes at the same time because the total memory size of the Mazzoni transceivers is only 26,890 bytes (as determined by the combined upstream and downstream bit rates of the A6 service). *See id.* at 4:18-22 and 6:45-50.

212. While Dr. Jacobsen's asserted motivations to combine LB-031 and Mazzoni fail to account for the fact that Mazzoni's transceivers are preconfigured at the time of installation with all the information they need, in another section (specifically in Section IX.G.5 of the Jacobsen Report) she admits that "Mazzoni further discloses keeping a table of values of the interleaver parameters, indexed by service identifies, in the transceiver." *See* Jacobsen Report at ¶ 626 (citing Mazzoni at 6:51-61).

213. A POSITA at the time of the Family 3 Patent inventions would not combine the teachings of Mazzoni with the teachings of LB-031. If fact, a POSITA would be discouraged from doing so. Because Mazzoni teaches that an assignment of the memory is performed at the time of the installation of the modem based on a table, and not a message, adding a message to this system per LB-031 would be unnecessary, redundant, and create useless complexity during initialization. Further, because Mazzoni is concerned with supporting a finite set of predefined service configurations (i.e., data rate pairs and corresponding interleaver/deinterleaver parameter values).

214. For at least the foregoing reasons, Dr. Jacobsen has not demonstrated that a POSITA would have been motivated to combine LB-031 with Mazzoni in the manner she proposes.

**3. The Combination of LB-031 and Mazzoni Does Not Render Claim 1 of the '048 Patent Obvious**

215. It is my opinion for the reasons provided in Section VI.B.2 above and as further discussed in this Section VI.B.3 below, that a POSITA would not combine LB-031 and Mazzoni or arrive at the claimed invention even if one were to attempt to combine these references in some way. It is further my opinion and conclusion that LB-031 in combination with Mazzoni fails to disclose each element of claim 1 of the '048 patent, and hence fails to render claim 1 of the '048 patent obvious as described in detail, below.

**a. The combination of LB-031 and Mazzoni does not disclose a system that allocates shared memory.**

216. As explained in Section VI.A.2.a, *supra*, LB-031 does not disclose a system that allocates shared memory. LB-031 also does not disclose the exchange of information that would be useful for allocating shared memory. As explain above, LB-031 only describes exchanging information about the maximum size of dedicated interleaver memory and, separately, the maximum size of dedicated deinterleaver memory supported by a transceiver. At least for the reasons explained, in paragraph 211 above, this information could not be used by a Mazzoni transceiver to allocate shared memory.

217. As explained above in the Overview of Mazzoni section, Mazzoni relies on a predetermined assignment of a service that has a predetermined pair of upstream and downstream bit rates and a corresponding set of predetermined interleaver and deinterleaver parameter values,  $I$ ,  $M$ ,  $I'$  and  $M'$ . See § VI.B.1. The predetermined assignment takes place when the modem is installed by retrieving the bit rates and parameter values from a stored table. Mazzoni at 6:55-69. Thus, contrary to Dr. Jacobsen's opinion, Mazzoni does not disclose exchanging any messages at all that include information about interleaving or deinterleaving parameters. See also, § VI.B.3.b, *infra*.

218. Mazzoni does not disclose the claimed system for allocating shared memory at least because Mazzoni does not disclose a transceiver that (1) transmits or receives a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver (see § VI.B.3.b, *infra*); (2) determining an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within the shared memory (see § VI.B.3.c, *infra*); and (3) allocating a first number of bytes of the shared memory to the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes in the message (see § VI.B.3.d, *infra*).

219. Also, because a POSITA would have no rational reason to combine the LB-031 with Mazzoni, as explained in Section VI.B.2, *supra*, the combination of the combination of LB-031 and Mazzoni does not render claim 1 of the '048 patent obvious.

- b. **The combination of LB-031 and Mazzoni does not disclose a transceiver that is capable of transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver.**

220. Contrary to Dr. Jacobsen's assertion, Mazzoni does not disclose exchanging any messages at all that include information about interleaving or deinterleaving parameters. Dr. Jacobsen asserts that "[o]ne of ordinary skill in the art would have understood that the bit rate information, as well as capabilities of the transceiver at the other end of the system, would have to be conveyed, for example, in the form of a message during initialization, as is described in LB-031. Jacobsen Report at ¶ 269. The "information" she is referring to is the parameters  $I$ ,  $M$ ,  $I'$  and  $M'$ . But, she cannot point to any disclosure of such a message in Mazzoni because there is no such disclosure. Instead, it seems that she is interpreting Mazzoni's description of the configurability of its interleaver means and deinterleaver means according to upstream and downstream bit rates as somehow disclosing reliance on an exchange of  $I$ ,  $M$ ,  $I'$  and  $M'$ . See *id.* (citing Mazzoni at 1:61-65 and 5:24-31). But parameters  $I$ ,  $M$ ,  $I'$  and  $M'$  are not exchanged in any message; rather, as discussed above in Section VI.B.1, these parameters are stored in a table in each transceiver and indexed to a predefined service that includes predefined upstream and downstream bit rates. Mazzoni at 6:53-61. The parameter values for the particular predefined service are retrieved by the control means MCD at the time the modem is installed (*id.*) and delivered by the MCD to the interleaver means MET and deinterleaver means MDET (*id.* at 5:21-23 and Fig. 3). This eliminates any need to exchange these parameters between modems.

221. One of the passages Dr. Jacobsen cites for this assertion, Mazzoni at column 5:24-31, does not describe some alternative embodiment where the I, M, I' and M' parameters are exchanged in messages. Rather, this passage simply describes the use of the predetermined parameters that are indexed to the predetermined service bit rates the transceiver has been configured to use. Dr. Jacobsen accurately admits this elsewhere in her report. *See, e.g.*, Jacobsen Report at ¶ 595 (“Mazzoni discloses keeping a table of values of the interleaver parameters, indexed by service identifiers, in the transceiver. *See id.* at col. 6:51-61. As a person having ordinary skill in the art as of the '473 patent's priority date would have understood, Mazzoni's table is limiting in that all of the services would have to be identified ahead of time and stored in the transceivers.”); *see also id.* at ¶ 626.

222. The other passage Dr. Jacobsen relies on for this assertion, Mazzoni at column 1:61-65, also does not disclose or require the exchange of any interleaver or deinterleaver parameters in a message. To the extent Dr. Jacobsen is interpreting this passage as disclosing anything other than the use of predetermined parameters that correspond to predetermined bit rates, she has misunderstood Mazzoni. In fact, the sentence after the one she quotes shows that the reference to “the bit rate actually processed by the send/receive device (modem)” is referring to one of the predetermined bit rates for a predetermined service. Mazzoni at 1:65 – 2:2 (“The invention therefore provides a device for sending/receiving digital data that is capable of *processing different bit rates from a group of predetermined bit rates* (e.g., all the symmetrical or asymmetrical services offered by the VDSL communication system).”).

223. Because Mazzoni does not describe any message specifying an amount of memory that can be allocated to an interleaver or to a deinterleaver, and because LB-031's exchange of interleaver and deinterleaver capabilities would be useless and incompatible with Mazzoni (*see* § VI.B.2, *supra*), the combination of LB-031 and Mazzoni does not disclose "a transceiver that is capable of transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver" and, at least for this reason, claim 1 of the '048 patent is not obvious in view of LB-031 and Mazzoni.

- c. **The combination of LB-031 and Mazzoni does not disclose a transceiver that is capable of determining an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within the shared memory.**

224. Dr. Jacobsen assert that Mazzoni discloses this limitation. I disagree. While Mazzoni describes the math calculations by which the interleaver and deinterleaver memory sizes can be determined from the upstream and downstream bit rates and the parameters  $I$ ,  $M$ ,  $I'$  and  $M'$  (*see* Mazzoni at 6:11-50), there is no disclosure in Mazzoni that these memory sizes or parameters are determined by Mazzoni's transceiver. Rather, these values are predetermined, stored in a table, and retrieved for use at the time of installation of the transceiver. *Id.* at 6:53-59 ("A table of values for the parameters  $I$ ,  $M$ ,  $I'$  and  $M'$  can therefore be stored in the coding/decoding stage. When the modem is installed . . . , the control means MCD may retrieve the corresponding values of  $I$ ,  $M$ ,  $I'$  and  $M'$  from the stored table."). Because these values are stored prior

to installation, they may be calculated by hand or by separate computer before loading into a stored table on the transceiver.

225. Simplification is a major benefit of Mazzoni's scheme of providing devices that are preconfigured to provide one of 12 service profiles with predetermined data rates and predetermined interleaver and deinterleaver parameters. Requiring Mazzoni's transceiver to calculate interleaver parameters or memory sizes each time it is going to use these values would be contrary to the goal of simplification, particularly where only a limited number of service profiles are needed and where all necessary information is stored prior to installation.

226. Because Mazzoni does not describe a transceiver that determines interleaver parameters or memory sizes, and because requiring Mazzoni to do so it would be contrary to Mazzoni's simplified scheme of storing predetermined values, the combination of LB-031 and Mazzoni does not disclose "a transceiver that is capable of determining an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within the shared memory" and, at least for this reason, claim 1 of the '048 patent is not obvious in view of LB-031 and Mazzoni.

227. Also, because a POSITA would be discouraged from combining the teaching of LB-031 with the teachings of Mazzoni, as explained in Section VI.B.2, *supra*, the combination of the combination of LB-031 and Mazzoni does not render claim 1 of the '048 patent obvious.

- d. **The combination of LB-031 and Mazzoni does not disclose a transceiver that is capable of allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes in the message.**

228. As explained in Section VI.A.2.c, *supra*, LB-031 does not disclose or suggest allocating the first number of bytes of the shared memory to the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes in the message. This is so at least because LB-031 does not disclose shared memory, as explained in Sections VI.A.1, VI.A.2.a, and VI.A.5.a.ii.

229. As explained in Section VI.B.3.b, *supra*, Mazzoni does not disclose transmitting or receiving any message with interleaver or deinterleaver parameters. Further, as explained in Section VI.B.2, *supra*, LB-031's exchange of interleaver and deinterleaver capabilities is redundant to Mazzoni's stored predefined service data rates and interleaver/deinterleaver parameters and incompatible with Mazzoni at least because the exchange of maximum supported interleaver and deinterleaver sizes per LB-031 would specify a combined amount of interleaver and deinterleaver memory that would exceed Mazzoni's total memory size. Accordingly, the combination of LB-031 and Mazzoni does not disclose "a transceiver that is capable of allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes in



the message” and, at least for this reason, claim 1 of the ‘048 patent is not obvious in view of LB-031 and Mazzoni.

230. I note that Dr. Jacobsen cites to Mazzoni at column 1:19-27 for purportedly disclosing the portion of this claim element that recites “wherein the allocated memory for the interleaver does not exceed the maximum number of bytes in the message.” Jacobsen Report at ¶ 280. She does not provide any explanation for how this portion of Mazzoni discloses this claim element. I have reviewed this portion of Mazzoni and it does not in any way disclose this claim element. Rather, it is a generic background section regarding VDSL, asymmetrical and symmetrical data rates, and the fact that modems that operate at predetermined bit rates have interleaver and deinterleaver memories that depend on that bit rate. This background section actually emphasizes, consistent with my opinions, that Mazzoni is directed to providing predefined services with predetermined bit rates and corresponding predefined interleaver and deinterleaver parameters, which would not require, or benefit from, an exchange of capabilities per LB-031.

#### **4. The Combination of LB-031 and Mazzoni Does Not Render Claim 5 of the ‘381 Patent Obvious**

231. It is my opinion for the reasons provided in Section VI.B.2 above and as further discussed in this Section VI.B.4, that a POSITA would not combine LB-031 and Mazzoni or arrive at the claimed invention even if one were to attempt to combine these references in some way. It is further my opinion and conclusion that LB-031 in

combination with Mazzoni fails to disclose each element of claim 5 of the '381 patent, and hence fails to render claim 5 of the '381 patent obvious as described in detail, below.

- a. **The combination of LB-031 and Mazzoni does not disclose a non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver.**

232. As explained in Section VI.A.3.a, *supra*, LB-031 does not disclose a non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver. *See also* § VI.A.2.a, *supra*; *see generally* § VI.A.1, *supra*.

233. More generally, LB-031 also does not disclose the exchange of information that would be useful for allocating shared memory. *See id.* As explained above, LB-031 only describes exchanging information about the maximum size of dedicated interleaver memory and, separately, the maximum size of dedicated deinterleaver memory supported by a transceiver. At least for the reasons explained, in paragraph 211 above, this information could not be used by a Mazzoni transceiver to allocate shared memory. As described in Section VI.A.2.a, LB-031 does not include any disclosure directed to allocating shared memory in a transceiver. Consequently, at least for the same reasons as described with respect to claim 1 of the '048 patent, LB-031 fails to disclose this element of claim 5 of the '381 patent.

234. As explained above in the Overview of Mazzoni section, Mazzoni relies on a predetermined assignment of a service that has a predetermined pair of upstream

and downstream bit rates and a corresponding set of predetermined interleaver and deinterleaver parameter values,  $I$ ,  $M$ ,  $I'$  and  $M'$ . See § VI.B.1. The predetermined assignment takes place when the modem is installed by retrieving the bit rates and parameter values from a stored table. Mazzoni at 6:55-69. Thus, contrary to Dr. Jacobsen's opinion with respect to claim 1 of the '048 patent (incorporated by reference here), Mazzoni does not disclose exchanging any messages at all that include information about interleaving or deinterleaving parameters as described above in connection with claim 1 of the '048 patent. See also, § VI.B.3.b, *supra*.

235. Furthermore, Dr. Jacobsen did not identify any portions of LB-031 that disclose a non-transitory computer-readable information storage media having stored thereon instruction that are executed by a processor in Section IX.B.4.a of the Jacobsen Report addressing this claimed element. Nor has she done that in Section IX.A.4.a of the Jacobsen Report, which seems relevant but was not even incorporated by reference. See Jacobsen Report at ¶ 210; see also *id.* at ¶ 300. With respect to LB-031, as explained in Section VI.A.3.a above, Dr. Jacobsen without any support simply draws an inference that “[o]ne of ordinary skill in the art would have understood that a source code and instructions for such transceivers could be stored on computer-readable information storage media, and could be executed by a processor.” See *id.* Dr. Jacobsen makes the same argument with respect to Mazzoni. See Jacobsen Report at ¶ 300 (“One of ordinary skill in the art would have understood that source code and instructions for such transceiver could be stored on computer-readable information storage media, and could be executed by a processor, for example, as source or object code.”).

236. As explained in Section VI.A.3.a, *supra*, Dr. Jacobsen's conclusion is wrong on its face. Source code (or object code) cannot be executed by a processor. A POSITA would understand that source code (or object code) is a term of art referring to uncompiled and non-executable human readable code.

237. Also, as explained in Section VI.A.3.a, *supra* with respect to LB-031, and now with respect to Mazzoni, even ignoring the fact that Dr. Jacobsen's conclusion is wrong on its face, Dr. Jacobsen did not show that any element of claim 5 of the '381 patent is performed by executing instructions stored on a non-transitory computer-readable information media. A POSITA would understand that it is possible that one or more of the claimed functions could be implemented in hardware, and therefore would not necessarily have to be carried out through an execution of instructions stored on a non-transitory computer-readable media. Dr. Jacobsen did not even attempt to show one way or another with which of these possibilities LB-031 or Mazzoni would be concerned with respect to each claimed function.

238. Finally, Mazzoni does not disclose the claimed non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver at least because Mazzoni does not disclose (1) transmitting or receiving, by the transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver (*see* § VI.B.4.b, *infra* and § VI.B.3.b, *supra*); (2) determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes

within a shared memory (*see* § VI.B.4.c, *infra* and § VI.B.3.c, *supra*); and (3) allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message (*see* § VI.B.4.d, *infra* and § VI.B.3.d, *supra*).

239. Also, because a POSITA would have no rational reason to combine the LB-031 with Mazzoni, as explained in Section VI.B.2, *supra*, the combination of the combination of LB-031 and Mazzoni does not render claim 5 of the '381 patent obvious.

240. It is my opinion that LB-031 does not disclose, teach, or suggest this claim element of claim 5 of the '381 patent and therefore fails to render claim 5 of the '381 Patent obvious.

**b. The combination of LB-031 and Mazzoni does not disclose transmitting or receiving, by the transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver.**

241. Contrary to Dr. Jacobsen's assertion, Mazzoni does not disclose exchanging any messages at all that include information about interleaving or deinterleaving parameters. Dr. Jacobsen asserts that her discussion with respect to an interleaver in Section IX.B.3.c is equally applicable to a deinterleaver. *See* Jacobsen Report at ¶ 303. I have addressed the arguments from that section in Section VI.B.3.b, *supra*.

242. Because Mazzoni does not describe any message specifying an amount of memory that can be allocated to an interleaver or to a deinterleaver, and because LB-031's exchange of interleaver and deinterleaver capabilities would be useless and incompatible with Mazzoni (*see* § VI.B.2, *supra*), the combination of LB-031 and Mazzoni does not disclose "transmitting or receiving, by the transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver" and, at least for this reason, claim 5 of the '381 patent is not obvious in view of LB-031 and Mazzoni.

- c. **The combination of LB-031 and Mazzoni does not disclose determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory.**

243. Dr. Jacobsen assert that Mazzoni discloses this limitation by incorporating her arguments from paragraph 269 of the Jacobsen Report. *See* Jacobsen Report at ¶ 305. I disagree for the reasons discussed in Section VI.B.3.c. My arguments directed to interleaving are equally applicable to deinterleaving.

244. Because Mazzoni does not describe a transceiver that determines deinterleaver parameters or memory sizes, and because requiring Mazzoni to do so it would be contrary to Mazzoni's simplified scheme of storing predetermined values, the combination of LB-031 and Mazzoni does not disclose "determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory" and, at least for this reason, claim 5 of the '381 patent is not obvious in view of LB-031 and Mazzoni.

245. Also, because a POSITA would be discouraged from combining the teaching of LB-031 with the teachings of Mazzoni, as explained in Section VI.B.2, *supra*, the combination of the combination of LB-031 and Mazzoni does not render claim 5 of the '381 patent obvious.

- d. The combination of LB-031 and Mazzoni does not disclose allocating, in the transceiver, a first number of bytes if the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message.**

246. As explained in Sections VI.A.3.c and VI.A.3.d, LB-031 does not disclose allocating, in the transceiver, a first number of bytes if the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message. This is so at least because LB-031 does not disclose shared memory, as explained in, for example, Sections VI.A.2.a, VI.A.5.a.ii.

247. As explained in Section VI.B.3.b, *supra*, Mazzoni does not disclose transmitting or receiving any message with interleaver or deinterleaver parameters. Further, as explained in Section VI.B.2, *supra*, LB-031's exchange of interleaver and deinterleaver capabilities is redundant to Mazzoni's stored predefined service data rates and interleaver/deinterleaver parameters and incompatible with Mazzoni at least because the exchange of maximum supported interleaver and deinterleaver sizes per LB-031 would specify a combined amount of interleaver and deinterleaver memory that

would exceed Mazzoni's total memory size. Accordingly, the combination of LB-031 and Mazzoni does not disclose "allocating, in the transceiver, a first number of bytes if the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message" and, at least for this reason, claim 5 of the '381 patent is not obvious in view of LB-031 and Mazzoni.

248. I also note that in a section incorporated by reference, Dr. Jacobsen cites to Mazzoni at column 1:19-27 for purportedly disclosing the portion of the claim element that recites "wherein the allocated memory for the *interleaver* does not exceed the maximum number of bytes in the message." Jacobsen Report at ¶ 280. She does not provide any explanation for how this portion of Mazzoni discloses this claim element. I have reviewed this portion of Mazzoni and it does not in any way disclose this claim element. Rather, it is a generic background section regarding VDSL, asymmetrical and symmetrical data rates, and the fact that modems that operate at predetermined bit rates have interleaver and deinterleaver memories that depend on that bit rate. This background section actually emphasizes, consistent with my opinions, that Mazzoni is directed to providing predefined services with predetermined bit rates and corresponding predefined interleaver and deinterleaver parameters, which would not require, or benefit from, an exchange of capabilities per LB-031. At least for the same reason, Mazzoni does not disclose this claim element that recites "wherein the allocated



memory for the *deinterleaver* does not exceed the maximum number of bytes specified in the message.”

**5. The Combination of LB-031 and Mazzoni Does Not Render Claim 13 of the ‘882 Patent Obvious**

249. It is my opinion for the reasons provided in Section VI.B.2 above and as further discussed in this Section VI.B.5, that a POSITA would not combine LB-031 and Mazzoni or arrive at the claimed invention even if one were to attempt to combine these references in some way. It is further my opinion and conclusion that LB-031 in combination with Mazzoni fails to disclose each element of claim 13 of the ‘882 patent, and hence fails to render claim 13 of the ‘882 patent obvious as described in detail, below.

**a. The Combination of LB-031 and Mazzoni does not disclose a system that allocates shared memory.**

250. LB-031 does not disclose, teach, or suggest this claim element of claim 13 of the ‘882 Patent for the same reason as discussed with respect to the same claim element of claim 1 of the ‘048 Patent. *See* § VI.B.3.a, *supra*.

**b. The Combination of LB-031 and Mazzoni does not disclose other elements of this claim.**

251. Dr. Jacobsen adopts wholesale her arguments with respect to claim 5 of the of the ‘381 patent (elements 5[b] – 5[h]) as her argument with respect to claim 13 of the ‘882 patent (elements 13[c] through 13[i], respectively). *See* Jacobsen Report at ¶ 320.

252. Accordingly, I hereby incorporate my arguments with respect to claim elements of claim 5 of the ‘381 patent, and also claim 1 of the ‘048 Patent as rebuttal argument for the respective claim elements of claim 13 of the ‘882 patent.

253. Specifically, using the claim element numbering from Dr. Jacobsen Report (see Appendix C to Jacobsen Report), I hereby incorporate herein the following sections of this report:

- with respect to elements 13[b] and 13[c], I incorporate §§ VI.B.3.b, VI.B.4.b, *supra*;
- with respect to elements 13[b] and 13[d], I incorporate §§ VI.B.3.c, VI.B.4.c, *supra*;
- with respect to elements 13[b], 13[e], and 13[f], I incorporate §§ VI.B.3.d, VI.B.4.d, *supra*;

254. The Combination of LB-031 and Mazzoni does not disclose, teach, or suggest the above claim elements of claim 13 of the '882 Patent for the same reason as discussed with respect to the substantially similar claim elements of claim 5 of the '381 Patent, and claim 1 of the '048 Patent. At least for these reasons, it is my opinion and conclusion that the Combination of LB-031 and Mazzoni fails to disclose or suggest all elements of claim 13 of the '882 Patent.

#### **6. The Combination of LB-031 and Mazzoni Does Not Render Claim 19 of the '473 Patent Obvious**

255. It is my opinion for the reasons provided in Section VI.B.2 above and as further discussed in this Section VI.B.6, that a POSITA would not combine LB-031 and Mazzoni or arrive at the claimed invention even if one were to attempt to combine these references in some way. It is further my opinion and conclusion that LB-031 in combination with Mazzoni fails to disclose each element of claim 19 of the '473 patent,

and hence fails to render claim 19 of the '473 patent obvious as described in detail, below.

- a. **The Combination of LB-031 and Mazzoni does not disclose a multicarrier transceiver being associated with a memory wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.**

256. For the reasons discussed above in Section VI.A.5.a, LB-031 does not disclose this claim element.

257. Further, contrary to Dr. Jacobsen's opinion, Mazzoni does not disclose exchanging any messages at all that include information about interleaving or deinterleaving parameters (or any other information upon which interleaver or deinterleaver memory allocations could be based). Dr. Jacobsen asserts that "[o]ne of ordinary skill in the art would have understood that this information, as well as capabilities of the transceiver at the other end of the system, would have to be conveyed, for example, in the form of a message during initialization, and that the memory would be allocated between the interleaving function and the deinterleaving function in accordance with that message." Jacobsen Report at ¶ 339. The "information" she is referring to is the parameters  $I$ ,  $M$ ,  $I'$  and  $M'$ . But, she cannot point to any disclosure of such a message in Mazzoni because there is no such disclosure. Instead, it seems that she is interpreting Mazzoni's description of the configurability of its interleaver means and deinterleaver means according to upstream and downstream bit rates as somehow disclosing reliance on an exchange of  $I$ ,  $M$ ,  $I'$  and  $M'$ . See *id.* (citing Mazzoni at 1:61-65 and 5:24-31). But parameters  $I$ ,  $M$ ,  $I'$  and  $M'$  are not exchanged in

any message; rather, as discussed above in Section VI.B.1, these parameters are stored in a table in each transceiver and indexed to a predefined service that includes predefined upstream and downstream bit rates. Mazzoni at 6:53-61. The parameter values for the particular predefined service are retrieved by the control means MCD at the time the modem is installed (*id.*) and delivered by the MCD to the interleaver means MET and deinterleaver means MDET (*id.* at 5:21-23 and Fig. 3). This eliminates any need to exchange these parameters between modems.

258. One of the passages Dr. Jacobsen cites for this assertion, Mazzoni at column 5:24-31, does not describe some alternative embodiment where the I, M, I' and M' parameters are exchanged in messages. Rather, this passage simply describes the use of the predetermined parameters that are indexed to the predetermined service bit rates the transceiver has been configured to use. Dr. Jacobsen accurately admits this elsewhere in her report. *See, e.g.,* Jacobsen Report at ¶ 595 (“Mazzoni discloses keeping a table of values of the interleaver parameters, indexed by service identifiers, in the transceiver. *See id.* at col. 6:51-61. As a person having ordinary skill in the art as of the ’473 patent’s priority date would have understood, Mazzoni’s table is limiting in that all of the services would have to be identified ahead of time and stored in the transceivers.”); *see also id.* at ¶ 626.

259. The other passage Dr. Jacobsen relies on for this assertion, Mazzoni at column 1:61-65, also does not disclose or require the exchange of any interleaver or deinterleaver parameters in a message. To the extent Dr. Jacobsen is interpreting this passage as disclosing anything other than the use of predetermined parameters that

correspond to predetermined bit rates, she has misunderstood Mazzoni. In fact, the sentence after the one she quotes shows that the reference to “the bit rate actually processed by the send/receive device (modem)” is referring to one of the predetermined bit rates for a predetermined service. Mazzoni at 1:65 – 2:2 (“The invention therefore provides a device for sending/receiving digital data that is capable of *processing different bit rates from a group of predetermined bit rates* (e.g., all the symmetrical or asymmetrical services offered by the VDSL communication system).”).

260. While neither LB-031 or Mazzoni individually disclose this claim element, as explained in Section VI.B.2, *supra*, LB-031’s exchange of interleaver and deinterleaver capabilities is redundant to Mazzoni’s stored predefined service data rates and interleaver/deinterleaver parameters and incompatible with Mazzoni at least because the exchange of maximum supported interleaver and deinterleaver sizes per LB-031 would specify a combined amount of interleaver and deinterleaver memory that would exceed Mazzoni’s total memory size. Accordingly, the combination of LB-031 and Mazzoni does not disclose “a multicarrier transceiver being associated with a memory wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver” and, at least for this reason, claim 19 of the ‘473 patent is not obvious in view of LB-031 and Mazzoni.

- b. The combination of LB-031 and Mazzoni does not disclose a multicarrier transceiver being associated with a memory wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.**

261. For the reasons discussed above in Section VI.A.5.b, LB-031 does not disclose this claim element.

262. With respect to Mazzoni, Dr. Jacobsen's conclusion in paragraph 343 of the Jacobsen Report that "[o]ne of ordinary skill in the art would have understood that the interleaving means and the deinterleaving means would operate at the same time" does not appear to address this claim element. That an interleaver and deinterleaver operate at the same time does not disclose or require that a portion of the memory be allocated to the interleaver function or deinterleaver function at any one particular time depending on the message. Perhaps this was a cut and paste error and was intended for the element of claim 5 of the '381 patent, which recites: "wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver."

263. Dr. Jacobsen further asserts paragraph 344 of the Jacobsen Report that "Mazzoni also discloses that the portion of the memory allocated to the interleaving function or the deinterleaving function at any one particular time is dependent on the message." I disagree. As I explained in the section immediately above, Mazzoni does not disclose exchanging any messages at all that include information about interleaving or deinterleaving parameters (or any other information upon which interleaver or deinterleaver memory allocations could be based). Further, as I explained in the section

immediately above and in Section VI.B.2, *supra*, LB-031's exchange of interleaver and deinterleaver capabilities is redundant to and incompatible with Mazzoni.

264. For at least the foregoing reasons, the combination of LB-031 and Mazzoni does not disclose "wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message" and, at least for this reason, claim 19 of the '473 patent is not obvious in view of LB-031 and Mazzoni.

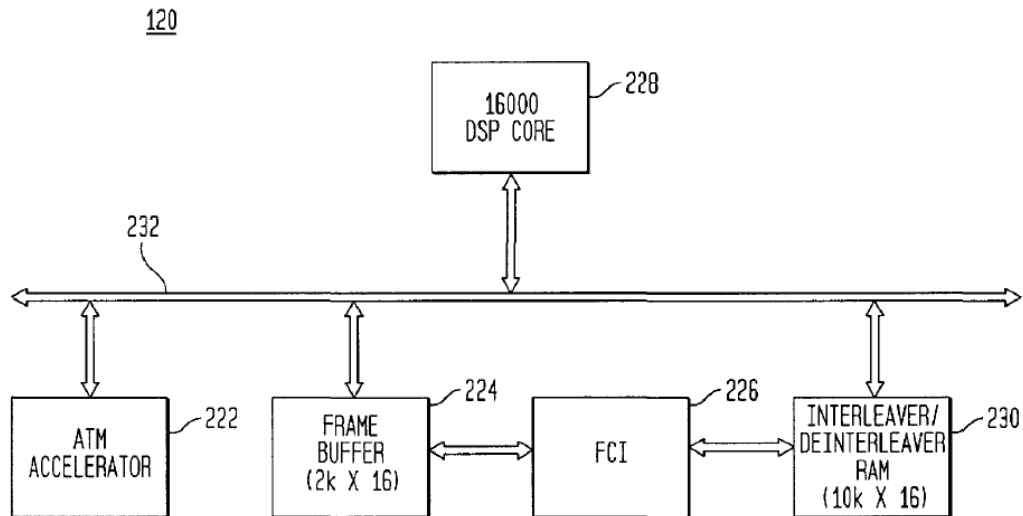
**C. The Asserted Claims Are Not Obvious Over Fadavi-Ardekani in Combination with ITU-T Recommendation G.993.1**

**1. Overview of Fadavi-Ardekani**

265. As an initial matter, U.S. Patent No. 6,707,822 to Fadavi-Ardekani et al., hereinafter Fadavi, was considered by the USPTO during the prosecution of the parent, U.S. Patent 7,831,890, and the claims were allowed over Fadavi. *See*, Notice of Allowance for '890 patent. Fadavi is also cited on the face of each of the Family 3 Patents.

266. Fadavi discloses "an Asymmetric Digital Subscriber Line (ADSL) transceiver that manages multiple asynchronous ADSL sessions, synchronizing the digital signal processing tasks for the sessions with a buffering and scheduling scheme such that the various transceiver components operate seamlessly (i.e., in a semi-synchronous fashion)." Fadavi at 2:62-68. Fadavi defines an agent as "a transceiver component for performing some function." *Id.* at 5:62-63. Fadavi discloses several

agents including the ATM accelerator, the Framer/Coder/Interleaver (FCI) and the DSP core. Set forth below is a block diagram of the transceiver taught by Fadavi.



Fadavi at FIG. 2.

267. The organization of the various agents and related components of Fadavi's transceiver is as follows:

An Asynchronous Transfer Mode (ATM) Accelerator provides the network interface to multiple ATM channels for multiple asynchronous ADSL sessions. The ATM accelerator transfers frame data to a Frame Buffer (FB) as controlled by a Digital Signal Processing (DSP) core. The FB provides a dual access memory that is used in a **ping-pang** fashion, based on the logic level of the virtual clock, for the communication of data between the ATM accelerator and a Framer/Coder/Interleaver (FCI). The FCI performs various processing tasks on the frame data and also interfaces the DSP core through an Interleave/De-interleave Memory (IDIM), which holds DMT frames of data and may also be utilized in a ping-pang fashion. . . . The DSP core controls operation of the ATM accelerator and the FCI and performs various processing tasks such as moving data to/from the FB and the IDIM.



Fadavi at 3:8-25 (emphasis added).

“Ping-pang” means that areas of the memory buffer are alternately utilized exclusively by one agent (a transceiver component for performing some function) and then by a second agent. As one area of memory is being used by a first agent, another area of memory can be used by a different agent.

*Id.* at 5:60-65.

The ATM accelerator provides those functions that are responsible for data transport for a plurality of data streams communicated via twisted pair media. The data may be transported on anyone of a plurality of programmable bearer channels. The data is synchronized into an appropriate one of the plurality of programmable bearer channels and the channels multiplexed in the ATM accelerator as determined by the ADSL standard. The ATM accelerator subjects this framed data to various operations that calculate a plurality of complex numbers representing DMT tones. The ATM accelerator subsequently transfers this DMT tone data on the twisted-pair media.

*Id.* at 5:43-54.

The FCI . . . performs various tasks on payload data including: framing/de-framing, cyclic redundancy check generation/checking (CRCing), scrambling/descrambling, Reed-Solomon encoding/decoding, and interleaving/de-interleaving. . . . All functionalities of the FCI are provided as per ADSL standards. In a preferred embodiment of the invention, approximately four G.lite (ITU G.992.2) or approximately four ADSL (ANSI T1.413-1998) sessions are supported by the FCI.

*Id.* at 6:20-23.

268. Fadavi explains that the FB and IDIM memories are accessed in ping-pang fashion by the agents. Specifically, [t]he Frame Buffer (FB) 224 provides a dual access memory that is used in a ping-pang fashion to transfer unframed bearer channel data between the ATM accelerator 222 and the FCI 226.” *Id.* at 5:57-60. The FCI and ATM accelerator first perform reading processes and then loading processes, reading RX data first before loading the TX data into the FB.

269. The IDIM is used in a ping-pang fashion by the FCI and DSP core.

Specifically,

The Interleave/De-Interleave Memory (IDIM) 230 provides a memory through which the FCI 226 interfaces the DSP core 228. The IDIM holds DMT frames of data and may be utilized in a ping-pang fashion. The IDIM is used to transfer framed, coded and possibly interleaved data frames between the FCI core and the DSP Core.

*Id.* at 6:55-60.

In a preferred embodiment of the invention, the IDIM is allocated as 10 Kx16 (i.e., 20 K) Random Access Memory (RAM), which supports approximately four G .lite or approximately four standard ADSL session/s at less than full interleave depth. The size of the IDIM and the interleave depth may be varied so that a different number of sessions may be supported by the transceiver of the invention. The size of the IDIM is derived as follows. A simple implementation of a transmit interleaver for G.lite communication requires 4 Kbytes per session for downstream processing, derived by multiplying the maximum codeword length by the maximum interleaver depth. The simple G.lite transmit interleaver also requires 2 Kbytes per session for upstream processing. Therefore, 24 Kbytes of RAM is required to support four G.lite sessions. Similarly, a simple implementation of a transmit interleaver for standard ADSL requires 16 Kbytes per session for downstream processing and 2 Kbytes per session for upstream processing, for a total of 72 Kbytes for four sessions. A fast path buffer is also required for fast path data in both the interleave and dc-interleave processes and requires 256 bytes of RAM per session, or a total of 1 Kbytes for four sessions. Since the smallest RAM block currently available is 1 Kx16, 1 Kx160 or 2 Kbytes must be allocated for the fast path buffer per direction. Therefore, a simple implementation of an interleaver would require 76 Kbytes for four standard ADSL sessions (64 K interleave +8 K de-interleave +4 K fast path). An optimal implementation of the interleaver according to the method of the invention utilizes the same memory for receive data and transmit data and thus requires 20 Kbytes to support a standard ADSL session at full interleave depth (16 K interleave & de-interleave +4 K fast path). With a lesser interleave depth, additional sessions may be supported with the same size buffer. With a larger buffer, additional session may be supported.

The IDIM is used in a ping-pang fashion by the FCI and DSP core.

270. Based on the foregoing, Fadavi teaches using an IDIM whose size is “derived by multiplying the maximum codeword length by the maximum interleaver depth.” To support additional sessions, Fadavi teaches reducing the interleaver depth or using a larger memory.

**2. Fadavi-Ardekani in combination with G.993.1 does not disclose all the limitations of claim 1 of the '048 patent**

**a. Fadavi-Ardekani does not disclose “a system that allocates shared memory”**

271. Dr. Jacobsen’s contends that the IDIM disclosed in Fadavi is the claimed shared memory, (Jacobsen Report at Id. at ¶ 371), and that the interleaving and deinterleaving functions in the FCI “share” the IDIM. *See*, Jacobsen Report at ¶¶ 390 and 400. The Court construed shared memory as “common memory used by at least two functions, where a portion of the memory can be used by either one of the functions.” As explained below, in view of Fadavi’s disclosure, the IDIM is not a common memory used by at least the interleaving and deinterleaving functions, where a portion of the memory can be used by either the interleaving or deinterleaving functions.

272. Fadavi teaches that:

The size of the IDIM is derived as follows. A simple implementation of a transmit interleaver for G.lite communication requires 4 Kbytes per session for downstream processing, derived by multiplying the maximum codeword length by the maximum interleaver depth. The simple G.lite transmit interleaver also requires 2 Kbytes per session for upstream processing. Therefore, 24 Kbytes of RAM is required to support four G.lite sessions. Similarly, a simple implementation of a transmit interleaver for standard ADSL requires 16 Kbytes per session for downstream processing and 2 Kbytes per session for upstream processing, for a total of 72 Kbytes

for four sessions. A fast path buffer is also required for fast path data in both the interleave and de-interleave processes and requires 256 bytes of RAM per session, or a total of 1 Kbytes for four sessions. Since the smallest RAM block currently available is 1Kx16, 1Kx160 or 2 Kbytes must be allocated for the fast path buffer per direction. Therefore, a simple implementation of an interleaver would require 76 Kbytes for four standard ADSL sessions (64 K interleave + 8 K de-interleave + 4 K fast path).

273. Based on the foregoing passage of Fadavi, a POSITA would understand that the size of the IDIM memory depends on the number of sessions/connections that the transceiver is designed to support. Fadavi at 7:6-10 (“**4 Kbytes** per session for downstream processing, . . . **2 Kbytes** per session for upstream processing. Therefore, **24 Kbytes** of RAM [ (4+2) x 4] is required to support **four** G.lite sessions.”). In an ADSL implementation, the transceiver is equipped with “76 Kbytes for four standard ADSL sessions (64 K interleave +8 K de-interleave +4 K fast path)”. *Id.* at 7:23-25. Fadavi explains that the memory sizes are “derived by **multiplying the maximum codeword length by the maximum interleaver depth.**” Fadavi at 7:8-10 (emphasis added). Given that the memory available for interleaving and deinterleaving is the maximum required by the DSL standards, the memory set aside for use by the interleaving function will never be used by the deinterleaving function. Even if the interleaving function uses less than all its memory, because for example, the far-end deinterleaver has lesser memory, the unused memory will not be used by the deinterleaving function because Fadavi contemplates that sufficient memory is set aside for use by the deinterleaver. Accordingly, a POSITA would understand that the IDIM described in Fadavi is not the claimed shared memory.

274. Dr. Jacobsen suggests that the IDIM is the claimed shared memory because Fadavi teaches that the IDIM “may be utilized in a ping-pang fashion.” Jacobsen Report at ¶ 371 (citing Fadavi at 6:57-58). I disagree that the ping-pang usage of the IDIM indicates that the IDIM is shared memory. Fadavi explains that ping-pang usage of the IDIM means that “[a]s one area of memory is being used by a first agent, another area of memory can be used by a different agent.” Fadavi at 5:60-65. “When the memory is used in ping-pang fashion, ‘[a]s long as different agents . . . access different areas of a dual access memory, there are no memory address conflicts that could cause communication errors.’” Jacobsen Report at Id. at ¶ 371 (citing Fadavi at 5:65-6:1). Thus, Fadavi merely teaches that the IDIM is a “dual access memory” and that an agent accesses its own area of the IDIM. Thus, although the IDIM is shared between different agents, for the reasons set forth at ¶ 273, the IDIM is not “shared memory,” as construed.

275. Fadavi also discloses “[a]n optimal implementation of the interleaver that utilizes the same memory for receive data and transmit data.” Fadavi at 7:25-30. To the extent, Dr. Jacobsen suggests that this “optimal implementation” teaches a shared memory, I disagree. The optimal implementation is incompatible with the DSL standards and accordingly a POSITA would not be motivated to use the optimal implementation, much less use the optimal implementation in combination with the G.993.1 standards. *See*, VI.C.6, *infra*.

- b. **Fadavi-Ardekani in combination with G.993.1 does not disclose “a transceiver capable of . . . allocating a first number of bytes of the shared memory to the interleaver . . . wherein the allocated memory for the interleaver does not exceed the maximum number of bytes specified in the message”**

276. As an initial matter, none of the sections of the G.993.1 standard that Dr. Jacobsen cites between ¶¶ 387-397 of the Jacobsen Report, suggests that a 993.1-compliant VTU-O necessarily includes a shared memory, *i.e.*, “common memory used by at least two functions, where a portion of the memory can be used by either one of the functions.” To the extent, Dr. Jacobsen suggests that G.993.1 at § 8.4.1 teaches “allocating a first number of bytes of the shared memory to the interleaver . . .” *See*, Jacobsen Report at ¶ 389, I disagree. § 8.4.1 provides that “[t]he interleave depth shall be programmable with a maximum interleave depth of 64 codewords when the number of octets per codeword (N) equals 255.” However, G.993.1 does not disclose or require the use of a “shared memory” by the interleaver and deinterleaver. For example, a transceiver could be designed with a fixed amount of memory that is used for interleaving, where the amount of memory corresponds to the maximum interleave depth mandated by the standard. Rather, a POSITA would understand G.993.1 to provide for dedicated downstream memories in each transceiver and separate, dedicated upstream memories in each transceiver. The use of such dedicated memories is consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems, including the LB-031 modem. *See* §§ IV and VI.A.5.a.ii, *supra*. As explained in these cited sections above, portions of dedicated interleaver memory that are not needed for interleaving cannot be allocated for use by the deinterleaver, and

vice versa. Instead, those portions simply go unused. *Id.* In fact, as described above at § VI.C.2.a, this is precisely the scheme disclosed in Fadavi.

277. Specifically, Fadavi teaches that “[t]he size of the IDIM . . . is derived by multiplying the *maximum codeword length* by the *maximum interleaver depth*.” Fadavi at 7:5-10. Thus, the interleaver in Fadavi is provided with a dedicated amount of memory and the interleaver may use as much as is needed based on the codeword length and interleaver depth. Similarly, the deinterleaver in Fadavi is provided with a dedicated amount of memory and the deinterleaver may use as much as is needed based on the codeword length and interleaver depth. Irrespective of the contents of the initialization messages transmitted or received, no portion of the IDIM set aside for use the interleaving function will ever be allocated for use by the deinterleaving function, and vice versa. And although initialization messages may be exchanged to communicate the capabilities of far-end transceiver, because Fadavi equips each of its interleaver and deinterleaver with the maximum amount of memory contemplated by the standard, there is no scenario where unused interleaving memory will be allocated for use by the deinterleaver, and vice versa.

278. Dr. Jacobsen incorrectly asserts that “[i]n allocating memory for each of the lines, Fadavi-Ardekani discloses determining the amount of memory to support different sessions required by the transceiver. *See*, Jacobsen Report at ¶ 396 (citing Fadavi at 7:3-33). This is a gross mischaracterization of the cited portion of Fadavi. Fadavi teaches using pre-determined amounts of memory derived by multiplying the *maximum codeword length* by the *maximum interleaver depth*, as mandated by the relevant

standard. Fadavi does teach that “with a lesser depth, additional sessions may be supported with the same size buffer” and “[w]ith a larger buffer, additional session[s] may be supported.” Fadavi at 7:30-33. However, this does not suggest that Fadavi allocates shared memory. This merely confirms that Fadavi uses pre-determined amounts of memory per session and precludes any need to use the content of the O-MSG2 message to allocate memory. Accordingly, I disagree with Dr. Jacobsen’s assertion at paragraph 396 that a POSITA “would have understood, based on the disclosures of Fadavi-Ardekani, that the allocated memory for the interleaver for each of the supported lines, which would have been determined based on the content of the O-MSG2 message transmitted by the VTU-O corresponding to that line, would not exceed the requirements the VTU-O set for itself in O-MSG2.”

279. Based on the foregoing, it is my opinion that the combination of Fadavi and G.993.1 does not disclose this limitation.

- c. **The combination of Fadavi-Ardekani and G.993.1 does not disclose “allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate”**

280. For at least the same reasons set forth in section VI.C.2.b, *supra*, my opinion is that the combination of Fadavi and G.993.1 does not disclose this claim element.



3. **Fadavi-Ardekani in combination with G.993.1 does not disclose all the limitations of claim 5 of the '381 patent**
  - a. **Fadavi-Ardekani does not disclose “a non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver”**

281. At least for the reasons set forth at § VI.C.2.a, *supra*, Fadavi does not include a “shared memory.” Accordingly, Fadavi cannot include “a non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver.”

- b. **Fadavi-Ardekani in combination with G.993.1 does not disclose “a transceiver capable of . . . allocating a first number of bytes of the shared memory to the deinterleaver . . . wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message”**

282. At least for the reasons articulated at § VI.C.2.b, *supra*, the combination of Fadavi and G.993.1 does not disclose this limitation. It is noteworthy and worth reiterating that Dr. Jacobsen merely asserts that “[o]ne of ordinary skill in the art would have understood that . . . allocating memory to an interleaver in Fadavi-Ardekani and G.993.1 apply equally to allocating memory to a deinterleaver.” Jacobsen Report at ¶ 142. Dr. Jacobsen does not contend that Fadavi and G.993.1 describe allocating shared memory.

- c. **Fadavi-Ardekani in combination with G.993.1 does not disclose “allocating a second number of bytes of the shared memory to a interleaver to interleave a second plurality of RS coded data bytes received at a second data rate”**

283. At least for the reasons articulated at § VI.C.2.b, *supra*, the combination of Fadavi and G.993.1 does not disclose this limitation.

- 4. **Fadavi-Ardekani in combination with G.993.1 does not disclose all the limitations of claim 13 of the '882 patent**

- a. **Fadavi-Ardekani does not disclose “a system that allocates shared memory”**

284. At least for the reasons set forth at § VI.C.2.a, *supra*, Fadavi does not include a “shared memory.” Accordingly, Fadavi does not disclose a system that allocates shared memory.

- b. **Fadavi-Ardekani in combination with G.993.1 does not disclose “a transceiver capable of . . . allocating a first number of bytes of the shared memory to the deinterleaver . . . wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message”**

285. At least for the reasons articulated at § VI.C.2.b, the combination of Fadavi and G.993.1 does not disclose this limitation.

- c. **Fadavi-Ardekani in combination with G.993.1 does not disclose “allocating a second number of bytes of the shared memory to a interleaver to interleave a second plurality of RS coded data bytes received at a second data rate”**

286. At least for the reasons articulated at § VI.C.2.b, the combination of Fadavi and G.993.1 does not disclose this limitation.

5. **Fadavi-Ardekani in combination with G.993.1 does not disclose all the limitations of claim 19 of the '473 patent**

- a. **The combination of Fadavi and G.993.1 does not disclose a multicarrier communications transceiver associated with a memory “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver”**

287. Fadavi does not disclose “allocating memory **between** an interleaving function and a deinterleaving function.” Dr. Jacobsen contends that the IDIM described in Fadavi is “allocate[ed] between an interleaving function and a deinterleaving function.” Jacobsen Report at ¶ 446. I disagree.

288. Dr. Jacobsen states that Fadavi teaches that “[a] portion of the memory is allocated to an interleaver by determining the size of the memory needed to interleave a certain amount of data.” Jacobsen Report at ¶ 447. Dr. Jacobsen mischaracterizes Fadavi. The interleaver is assigned a pre-determined amount of memory the size of which “is derived by multiplying the maximum codeword length by the maximum interleaver depth.” Fadavi at 7:5-10.

289. Dr. Jacobsen contends that the ping-pang usage of the IDIM means that the “memory is allocated between the interleaving function and the deinterleaving function” Jacobsen Report at ¶ 446. However, the claims require that the allocation of memory between the interleaving function and the deinterleaving function take place *in accordance with a message received during initialization*. Dr. Jacobsen has not alleged that such is the case in Fadavi.

290. Dr. Jacobsen also contends that a transceiver can use the parameters specified in the O-MSG2 and R-MSG2 messages described in the G.993.1 standard, “to allocate memory between an interleaver and a deinterleaver.” Jacobsen Report at ¶¶ 447-448. Rather, a POSITA would understand G.993.1 to provide for dedicated downstream memories in each transceiver and separate, dedicated upstream memories in each transceiver. The use of such dedicated memories is consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems, including the LB-031 modem. *See* §§ IV and VI.A.5.a.ii, *supra*). As explained in these cited sections above, portions of dedicated interleaver memory that are not needed for interleaving cannot be allocated for use by the deinterleaver, and vice versa. Instead, those portions simply go unused. *Id.*

291. Additionally, as previously explained, the transceiver described in Fadavi is designed such that the interleaver and deinterleaver are each provided with a pre-determined amount of memory that equates to the maximum amounts mandated by the standards. If the interleaver uses less than its assigned memory for any reason, the unused memory is not used by the deinterleaver because the deinterleaver is provided with a pre-determined amount of memory that equates to the maximum amount it may require. Thus, the IDIM is not allocated between the interleaving and deinterleaving functions. Accordingly, even if Fadavi is modified to use the O-MSG2 and R-MSG2, the IDIM would not be “allocated *between* the interleaving function and the deinterleaving function in accordance with” these messages.

- b. **The combination of Fadavi and G.993.1 does not disclose a multicarrier communications transceiver associated with a memory “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message”**

292. Fadavi does not disclose this limitation. As I previously explained, the interleaving and deinterleaving functions in Fadavi are each assigned a pre-determined amount of memory “derived by multiplying the maximum codeword length by the maximum interleaver depth.” Fadavi at 7:5-10. Given that each function is provided with its maximum memory requirement, there is no situation where a portion of the memory assigned to the interleaving function may be allocated to the deinterleaving function and vice versa.

293. With respect to the G.993.1 standard, Dr. Jacobsen contends that because “G.993.1 uses Frequency Division Duplexing (FDD),” “data would need to be interleaved and deinterleaved at the same time in this mode of transmission, which would require that a portion of the memory be allocated to an interleaving function, and a portion of the memory would be allocated to a deinterleaving function.” Jacobsen Report at ¶ 452. Based on this, Dr. Jacobsen concludes that “G.993.1 discloses that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time.” *Id.* I disagree. The claim requires that “at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.” The claim limitation is not met simply when “a portion of the memory [is] allocated to an

interleaving function, and a portion of the memory [is] allocated to a deinterleaving function,” as Dr. Jacobsen apparently contends.

294. Accordingly, it is my opinion that the combination of Fadavi-Ardekani and G.993.1 does not disclose this limitation.

**6. A POSITA would not have been motivated to combine Fadavi-Ardekani and G.993.1**

295. For the following reasons, I disagree with Dr. Jacobsen’s assertion at paragraphs 454-459 of the Jacobsen Report that “one of ordinary skill in the art as of the Family 3 patents’ priority date would have been motivated to combine the teachings of Fadavi-Ardekani with the teachings of G.993.1 in the manner claimed.”

296. First, Dr. Jacobsen asserts that that there is a motivation to combine because both references are in the telecommunications field and relate to DSL systems. See Jacobsen Report at ¶ 454. This in and of itself, or in combination with any other argument made by Dr. Jacobsen in Section IX.C.7 of the Jacobsen Report, is not sufficient show that a person of ordinary skill in the art would have combined the teachings of the two references. That both references are in the telecommunications field is simply far too broad and general of a field to say that that a POSITA would be motivated to combine any one of the many thousands of diverse telecommunications techniques, or any particular feature or function thereof. Further, at the time of the inventions of the Family 3 Patents, the DSL standards were under continuous development and there were likely hundreds, if not thousands, of references directed to possible implementation details of many and varied proposals for DSL transceivers.

One of skill in the art at the time would have understood that many of these references would be completely incompatible with one another and/or, if combined, would provide no useful benefit. Thus, that Fadavi and G.993.1 are purportedly both directed to different proposals for DSL transceivers, would not have made their combination obvious.

297. I further disagree with Dr. Jacobsen's premise that both Fadavi and G.993.1 describe the need to allocate memory for interleaving and deinterleaving functions. Dr. Jacobsen's opinion that "[o]ne of ordinary skill in the art naturally would have consulted Fadavi-Ardekani for its description of calculating memory needs and allocating memory between interleaver and deinterleaver functions" is not supported by the disclosure of Fadavi. Jacobsen Report at ¶ 456. Contrary to Dr. Jacobsen's assertion, Fadavi merely teaches providing each interleaver and deinterleaver with a dedicated amount of memory, the size of which is "derived by multiplying the maximum codeword length by the maximum interleaver depth." At least for this reason, a POSITA would not be motivated to modify Fadavi, to allocate memory based on the initialization messages described in G.993.1.

298. Dr. Jacobsen relies on the "optimal implementation of the interleaver" described in Fadavi to demonstrate that Fadavi includes a shared memory. Specifically, Dr. Jacobsen asserts that "Fadavi-Ardekani further describes allocating the IDIM memory between transmit and receive functions." Jacobsen Report at ¶ 372 (citing Fadavi at 7:25-30 ("An optimal implementation of the interleaver according to the method of the invention utilizes the same memory for receive data and transmit data

and thus requires 20 Kbytes to support a standard ADSL session at full interleave depth (16 K interleave & de-interleave +4 K fast path)."). It is my opinion that a POSITA would recognize that this implementation would be inoperable with G.993.1.

299. In the optimal implementation, Fadavi discloses that the same memory is used for receive and transmit data, alternately. Data received (deinterleave data) during one cycle will be overwritten by transmit data (interleave data) during a subsequent cycle. The G.993.1 standard requires that "[t]he interleave depth shall be programmable with a maximum interleave depth of 64 codewords when the number of octets per codeword (N) equals 255." G.993.1 at § 8.4.1. A POSITA would recognize that a codeword, after interleaving, will necessarily span multiple (typically many) DMT frames and that all the DMT frames will not be received during one cycle. Consequently, the deinterleaving operation cannot be completed during that cycle. However, during the next cycle the received deinterleave data will be overwritten with interleave data that must be interleaved and transmitted. This means that received data will not be correctly deinterleaved. For this reason, a POSITA would not have combined the teachings of the G.993.1 and Fadavi.

300. I also disagree with Dr. Jacobsen's assertion that a skilled artisan would have been motivated to combine the size- and cost-saving approach of Fadavi-Ardekani with the transceivers of G.993.1 to reduce the cost, size, and power consumption of the VTU-Os that would be deployed in optical network units or cabinets. Jacobsen Report at ¶ 457. A POSITA would recognize that modifying Fadavi to use the initialization messages described in G.993.1 would add to complexity. Further, in view of that fact



that the memory sizes in Fadavi are “derived by multiplying the maximum codeword length by the maximum interleaver depth,” processing and using the initialization messages of G.993.1 would bring no benefit to Fadavi.

301. For these reasons, a POSITA would not be motivated to combine the teachings of Fadavi and G.993.1.

**D. The Asserted Claims Are Not Obvious Over Fadavi-Ardekani in Combination with ITU-T Recommendation G.992.2**

**1. Fadavi-Ardekani in combination with G.992.1 does not disclose all the limitations of claim 1 of the '048 patent**

**a. Fadavi-Ardekani does not disclose “a system that allocates shared memory”**

302. For the reasons set forth at § VI.C.2.a, *supra*, Fadavi-Ardekani does not disclose “a system that allocates shared memory.”

**b. Fadavi-Ardekani in combination with G.992.2 does not disclose “a transceiver capable of . . . allocating a first number of bytes of the shared memory to the interleaver . . . wherein the allocated memory for the interleaver does not exceed the maximum number of bytes specified in the message”**

303. For the reasons set forth at § VI.C.2.b, *supra*, I disagree that Fadavi’s system includes the capability to “allocat[e] a first number of bytes of the shared memory to a interleaver” much less the capability to “allocat[e] a first number of bytes of the shared memory” such that “the allocated memory . . . does not exceed the maximum number of bytes specified in the message.”

304. Separately, Dr. Jacobsen contends that C-RATES1, R-RATES1, C-RATES-RA, R-RATES2 and C-RATES2 messages “can be used to allocate memory to implement” the interleaver. However, Dr. Jacobsen neglects to consider the plain

meaning of the claims. The claims require allocating bytes of the shared memory, where the shared memory is “common memory used by at least two functions where a portion of the memory can be used by either one of the functions.” Like the G.993.1 standard, the G.992.2 standard does not require that a transceiver implement a “shared memory” much less “allocat[e] a first number of bytes of the shared memory to an interleaver.” Rather, a POSITA would understand G.992.2 to provide for dedicated downstream memories in each transceiver and separate, dedicated upstream memories in each transceiver. The use of such dedicated memories is consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems, including the LB-031 modem. *See* §§ IV and VI.A.5.a.ii, *supra*. As explained in these cited sections above, portions of dedicated interleaver memory that are not needed for interleaving cannot be allocated for use by the deinterleaver, and vice versa. Instead, those portions simply go unused. *Id.* Accordingly, the combination of Fadavi and the G.992.2 does not disclose this claim limitation.

- c. **Fadavi-Ardekani in combination with G.992.2 does not disclose “allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate”**

305. For at least the same reasons set forth at § VI.D.1.b, *supra*, my opinion is that the combination of Fadavi and G.992.2 does not disclose this claim element.

**2. Fadavi-Ardekani in combination with G.992.2 does not disclose all the limitations of claim 5 of the '381 patent**

- a. Fadavi-Ardekani does not disclose “a non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver”**

306. At least for the reasons set forth at §§ VI.C.2.a and VI.C.3.a, Fadavi does not disclose this element.

- b. Fadavi-Ardekani in combination with G.992.2 does not disclose “a transceiver capable of . . . allocating a first number of bytes of the shared memory to the deinterleaver . . . wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message”**

307. For the reasons set forth at § VI.D.1.b, the combination of Fadavi and G.992.2 does not disclose this element.

- c. Fadavi-Ardekani in combination with G.992.2 does not disclose “allocating a second number of bytes of the shared memory to a interleaver to interleave a second plurality of RS coded data bytes received at a second data rate”**

308. For the reasons set forth at § VI.D.1.b, *supra*, the combination of Fadavi and G.992.2 does not disclose this element.

**3. Fadavi-Ardekani in combination with G.992.2 does not disclose all the limitation of claim 13 of the '882 patent**

- a. Fadavi-Ardekani does not disclose “a system that allocates shared memory”**

309. For the reasons set forth at § VI.C.2.a, *supra*, Fadavi-Ardekani does not disclose “a system that allocates shared memory.”

- b. **Fadavi-Ardekani in combination with G.992.2 does not disclose “a transceiver capable of . . . allocating a first number of bytes of the shared memory to the deinterleaver . . . wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message”**

310. For the reasons set forth at § VI.D.1.b, *supra*, the combination of Fadavi and G.992.2 does not disclose this element.

- c. **Fadavi-Ardekani in combination with G.992.2 does not disclose “allocating a second number of bytes of the shared memory to a interleaver to interleave a second plurality of RS coded data bytes received at a second data rate”**

311. For the reasons set forth at § VI.D.1.b, *supra*, the combination of Fadavi and G.992.2 does not disclose this element.

- 4. **Fadavi-Ardekani in combination with G.992.2 does not disclose all the limitation of claim 19 of the '473 patent**

- a. **The combination of Fadavi and G.992.2 does not disclose a multicarrier communications transceiver associated with a memory “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver”**

312. For the reasons set forth at § VI.C.5.a, *supra*, Fadavi does not disclose this element. Separately, the G.992.2 standard does not disclose this limitation. Dr. Jacobsen contends that certain initialization messages “can be used to allocate memory between an interleaver and a deinterleaver.” Jacobsen Report at ¶ 524. The G.992.2 standard, however, does not teach using the initialization messages to allocate memory between an interleaver and a deinterleaver. Rather, a POSITA would understand G.992.2 to provide for dedicated downstream memories in each transceiver and separate, dedicated upstream memories in each transceiver. The use of such dedicated

memories is consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems, including the LB-031 modem. *See* §§ IV and VI.A.5.a.ii, *supra*. As explained in these cited sections above, portions of dedicated interleaver memory that are not needed for interleaving cannot be allocated for use by the deinterleaver, and vice versa. Instead, those portions simply go unused. *Id.*

**b. The combination of Fadavi and G.992.2 does not disclose a multicarrier communications transceiver associated with a memory “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message”**

313. Fadavi does not disclose this limitation. *See* § VI.C.5.b, *supra*.

314. With respect to the G.992.2 standard, Dr. Jacobsen contends that because G.992.2 establishes a “single duplex bearer channel,” one of ordinary skill in the art would have understood that data is transmitted in both directions at the same time and as a result, the interleaver and deinterleaver are both used at the same time. Jacobsen Report at ¶ 526. Based on this, Dr. Jacobsen concludes that G.992.2 discloses that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time. *Id.* I disagree. The claim requires that “at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.” The claim limitation is not met simply when a portion of the memory is allocated to an interleaving function, and a portion of the memory is allocated to a deinterleaving function,” as Dr. Jacobsen apparently contends.

315. Accordingly, it is my opinion that the combination of Fadavi-Ardekani and G.992.2 does not disclose this limitation.

**5. A POSITA would not have been motivated to combine Fadavi-Ardekani and G.992.2**

316. For the following reasons, I disagree with Dr. Jacobsen's assertion at paragraphs 527-531 of the Jacobsen Report that "one of ordinary skill in the art as of the Family 3 patents' priority date would have been motivated to combine the teachings of Fadavi-Ardekani with the teachings of G.992.2 in the manner claimed."

317. First, Dr. Jacobsen asserts that that there is a motivation to combine because both references are in the telecommunications field and relate to ADSL systems. *See* Jacobsen Report at ¶ 527. This in and of itself, or in combination with any other argument made by Dr. Jacobsen in Section IX.D.6 of the Jacobsen Report, is not sufficient show that a person of ordinary skill in the art would have combined the teachings of the two references. That both references are in the telecommunications field is simply far too broad and general of a field to say that that a POSITA would be motivated to combine any one of the many thousands of diverse telecommunications techniques, or any particular feature or function thereof. Further, at the time of the inventions of the Family 3 Patents, the DSL standards were under continuous development and there were likely hundreds, if not thousands, of references directed to possible implementation details of many and varied proposals for DSL transceivers. One of skill in the art at the time would have understood that many of these references would be completely incompatible with one another and/or, if combined, would

provide no useful benefit. Thus, that Fadavi and G.992.2 are purportedly both directed to different proposals for DSL transceivers, would not have made their combination obvious.

318. I further disagree with Dr. Jacobsen's premise that both Fadavi and G.992.2 describe the need to allocate memory for interleaving and deinterleaving functions. Dr. Jacobsen opinion that "[o]ne of ordinary skill in the art naturally would have consulted Fadavi-Ardekani for its description of calculating memory needs and allocating memory between interleaver and deinterleaver functions" is not supported by the disclosure of Fadavi. Jacobsen Report at ¶ 528. Contrary to Dr. Jacobsen's assertion, Fadavi merely teaches providing each interleaver and deinterleaver with a dedicated amount of memory, the size of which is "derived by multiplying the maximum codeword length by the maximum interleaver depth." At least for this reason, a POSITA would not be motivated to modify Fadavi, to allocate memory based on the initialization messages described in G.992.2.

319. Dr. Jacobsen relies on the "optimal implementation of the interleaver" described in Fadavi to demonstrate that Fadavi includes a shared memory. Specifically, Dr. Jacobsen asserts that "Fadavi-Ardekani further describes allocating the IDIM memory between transmit and receive functions." Jacobsen Report at ¶ 372 (citing Fadavi at 7:25-30 ("An optimal implementation of the interleaver according to the method of the invention utilizes the same memory for receive data and transmit data and thus requires 20 Kbytes to support a standard ADSL session at full interleave depth

(16 K interleave & de-interleave +4 K fast path)."). It is my opinion that a POSITA would recognize that this implementation would be inoperable with G.992.2.

320. In the optimal implementation, Fadavi discloses that the same memory is used for receive and transmit data, alternately. Data received (deinterleave data) during one cycle will be overwritten by transmit data (interleave data) during a subsequent cycle. The G.992.2 standard requires that "The Reed-Solomon codewords shall be convolutionally interleaved." G.992.2 at § 7.6. A POSITA would recognize that a codeword, after interleaving, will necessarily span multiple (typically many) DMT frames and that all the DMT frames will not be received during one cycle. Consequently, the deinterleaving operation cannot be completed during that cycle. However, during the next cycle the received deinterleave data will be overwritten with interleave data that must be interleaved and transmitted. This means that received data will not be correctly deinterleaved. For this reason, a POSITA will be dissuaded from combining the teachings of the G.992.2 and Fadavi.

321. Separately, a POSITA would recognize that modifying Fadavi to use the initialization messages described in G.992.2 would add to complexity. Further, in view of that fact that the memory sizes in Fadavi are "derived by multiplying the maximum codeword length by the maximum interleaver depth," processing and using the initialization messages of G.992.2 would bring no benefit to Fadavi.

322. For these reasons, a POSITA would not be motivated to combine the teachings of Fadavi and G.992.2.



**E. Claim 19 of the '473 Patent Is Not Obvious Over Voith in Combination with LB-031**

323. It is my opinion and conclusion that Voith alone or in combination with LB-031 fails to disclose or suggest each element of the claim 19 of the '473 patent, and hence fails to render the claim 19 of the '473 patent obvious as described in detail, below.

324. It is also my opinion that regardless of the disclosures of Voith and LB-031 individually, a person of ordinary skill in the art would not be motivated to combine the teachings of Voith with the teachings of LB-031 at least for the reasons described in Section VI.E.3, *infra*.

325. An overview of LB-031 has been provided in Section VI.A.1, *supra*.

- 1. Neither Voith nor LB-031 discloses a multicarrier communications transceiver associated with a memory “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver”**

326. Dr. Jacobsen contends that “Voith discloses allocating memory between the interleaving function and the dinterleaving (sic) function” because Voith states that the interleaver “uses a portion of external interleave/deinterleave memory 66.” Jacobsen Report at ¶ 557 (citing Voith at 5:65-61). This is not correct. It does not follow from the fact that the external memory is used for both interleaving and deinterleaving that any portion of the memory is allocated *between* these functions.

327. Dr. Jacobsen has not shown that any portion of the interleave/deinterleave memory 66 is disclosed by Voith to be used as interleaver memory at one point in time and deinterleaver memory at another point in time.

Therefore, there is no basis for concluding that Voith allocates memory between an interleaving function and a deinterleaving function. Rather, a POSITA reviewing Voith's disclosure of an external interleave/deinterleave memory 66, would understand this as disclosing that the memory includes a dedicated portion for use by interleaver 78 and a separate, dedicated portion for use by deinterleaver 90. Such a predetermined division of separate, dedicated memories is consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems, including the LB-031 modem. *See* §§ IV and VI.A.5.a.ii, *supra*. As explained in these cited sections above, portions of dedicated interleaver memory that are not needed for interleaving cannot be allocated for use by the deinterleaver, and vice versa. Instead, those portions simply go unused. *Id.*

328. Further, Voith does not disclose performing any allocation of interleaver or deinterleaver memory "in accordance with a message received during an initialization of the transceiver." The only reference to a "message" in Dr. Jacobsen analysis for this claim element is the single conclusory sentence that "the bit allocation table is determined during initialization by the receiving transceiver and communicated to the transmitting transceiver in a message sent during the initialization procedure." Jacobsen Report at ¶ 558. Dr. Jacobsen appears to be relying on a message such as the O-B&G message described in the G.993.1 standard (§ 12.4.6.2.1.3 ("O-B&G shall signal the end of the contract negotiation and shall be used to transmit to the VTU-R the bits and the gains information that are to be used in the upstream direction.")) or the C-B&G message described in the G.992.2 standard (§ 11.11.13) as a message used for the

claimed memory allocation. However, Dr. Jacobsen provides no evidence that Voith teaches that ADSL transceiver 34 allocates memory 66 between the interleaver 78 and the deinterleaver 90 based on a bit-allocation message. Accordingly, I disagree that “Voith discloses wherein the *memory is allocated* between the interleaving function and the deinterleaving function *in accordance with a message received during an initialization of the transceiver*,” as Dr. Jacobsen alleges. Jacobsen Report at ¶ 558.

329. With respect to LB-031, as I previously explained at § VI.A.5.a, *supra*, LB-031 does not disclose this element. Specifically, LB-031 only teaches that the “VTU-O and VTU-R would then select the smaller of the transmitter and receiver capabilities in each direction, as the end-to-end capabilities.” LB-031 at p. 3. Accordingly, LB-031 at most discloses that a VTU-O (or a VTU-R) determines whether it can use all of its predetermined maximum interleaver memory or whether it has to use less of it because of the maximum capabilities of the deinterleaver on the other side of the line, are smaller. However, LB-031 does not teach that the unused portion of the interleaver memory can be allocated to the deinterleaver. Accordingly, LB-031 does not teach “the memory is allocated *between* the interleaving function and the deinterleaving function depending on a message.”

330. Accordingly, it is my opinion that neither Voith nor LB-031, alone or in combination, discloses this limitation.

2. **Neither Voith nor LB-031 discloses a multicarrier communications transceiver associated with a memory “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message”**

331. Voith does not disclose this limitation. Voith merely teaches that a first portion of memory 66 is used by the interleaver 78 and a second portion of memory 66 is used by the deinterleaver 90. Voith does not teach that this apportioning is performed based on a message. *See Supra* at ¶ 367. Additionally, Voith does not teach that any portion of the memory 66 may be allocated to the interleaver 78 *or* the deinterleaver 90 at any one particular time depending on a message.

332. Dr. Jacobsen has not pointed to any disclosure or teaching in Voith that states, or necessarily requires, that it uses memory where any portion is shared between an interleaving function and a deinterleaving function. Rather, a POSITA reviewing Voith’s disclosure of an external interleave/deinterleave memory 66, would understand this as disclosing that the memory includes a dedicated portion for use by interleaver 78 and a separate, dedicated portion for use by deinterleaver 90. Such a predetermined division of separate, dedicated memories is consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems, including the LB-031 modem *See* §§ IV and VI.A.5.a.ii, *supra*. As explained in these cited sections above, portions of dedicated interleaver memory that are not needed for interleaving cannot be allocated for use by the deinterleaver, and vice versa. Instead, those portions simply go unused. *Id.*

333. Dr. Jacobsen asserts that a POSITA would interpret Voith, including the sentences “[i]nterleaver 78 arbitrates for use of external interleave/deinterleave memory 66 with the deinterleaver 90” (Voith at 6:1-4) and “deinterleaver 90 makes use of external interleave/deinterleave memory 66 and arbitrates for usage thereof in a manner similar to interleaver 78” (*id.* at 26-29), as disclosing that “a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time.” Jacobsen Report at ¶¶ 557 and 562. I disagree. These sentences only mean that the interleaver 78 and deinterleaver 90 contend for access to the “external memory interface” in order to access external memory 66. Such contention for access to the external memory interface in general does not indicate in any way that the interleaver 78 and deinterleaver 90 are contending for or using, or capable of contending for or using, the same portions of the memory.

334. With reference to LB-031, for the same reasons set forth at Section VI.A.5.a and b, *supra*, LB-031 does not disclose this limitation.

### **3. No Motivation to Combine Voith with LB-031**

335. For the following reasons, I disagree with Dr. Jacobsen’s assertion at paragraphs 566-568 of the Jacobsen Report that “one of ordinary skill in the art would have been motivated to combine Voith and LB-031.”

336. First, Dr. Jacobsen asserts that that there is a motivation to combine because both references are “in the telecommunications field.” Jacobsen Report at ¶ 566. This in and of itself, or in combination with any other argument made by Dr. Jacobsen in Section IX.E.3 of the Jacobsen Report, is not sufficient show that a person of

ordinary skill in the art would have combined the teachings of the two references. This is simply far too broad and general of a field to say that that a POSITA would be motivated to combine any one of the many thousands of diverse telecommunications techniques, or any particular feature or function thereof.

337. Dr. Jacobsen further asserts that there is a motivation to combine because each of the references purportedly “discloses sharing memory for interleaving and deinterleaving to support various applications.” *Id.* at ¶ 566. This in and of itself, or in combination with any other argument made by Dr. Jacobsen in Section IX.E.3 of the Jacobsen Report, is not sufficient to motivate a person of ordinary skill in the art to combine the teaching of the two references.

338. Also, this assertion is not accurate. As explained in VI.A.1, *supra*, LB-031 is concerned with providing a solution that meets certain delay requirements specified in units of time, while allowing use of larger dedicated interleaver or deinterleaver memories if both transceivers support more than the minimum required by a standard. There is no technique described in LB-031 for “sharing memory for interleaving and deinterleaving to support various applications,” contrary to Dr. Jacobsen assertions. *See* § VI.A.1., *supra*. Rather, as I explained above, LB-031 describes a dedicated interleaver memory and a separate, dedicated deinterleaver memory where portions of a dedicated memory that is left unused by one function – because one transceiver supports more memory for a given latency path than is supported by the other transceiver with which it is communicating – is not available for use by the other function.. *See* § VI.A.5.a and ¶¶ 169-178, *supra*.

339. Voith also does not disclose “sharing memory for interleaving and deinterleaving to support various applications.” Jacobsen Report at ¶ 567. Voith merely teaches that it is preferable to implement the memory buffers off-chip, because “large buffers consume a large integrated circuit area which adds to its cost.” Voith at 2:27-28. Thus, Voith’s fundamental premise is to concede that the memory buffers are required to be large but Voith makes no proposal for reducing such requirement. Voith certainly does not propose the use of sharing memory for interleaving and deinterleaving where a portion of the memory can be used at one time for interleaving and at another time for deinterleaving as explained immediately above in sections VI.E.1 and 2.

340. Therefore, it is my opinion that a POSITA would not be motivated to combine Voith and LB-031, particularly not in any manner “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.”

**F. Claim 19 of the '473 Patent Is Not Obvious Over Mazzoni and G.993.1**

**1. A Person of Ordinary Skill in the Art Would Not Combine the Teachings of Mazzoni with the Teachings of G.993.1**

341. A person of ordinary skill in the art at the time of the invention of the Family 3 Patents would not look to the teachings of Mazzoni when implementing the teachings of G.993.1, or *vice versa*. In fact, as explained below, the two references are so different that a person of ordinary skill in the art would be discouraged from looking to the teaching of the other reference.

342. The overview of Mazzoni has been provided in Section VI.B.1, *supra*.

343. G.993.1, akin to LB-031, is yet another reference that employs a dedicated interleaver memory and a dedicated deinterleaver memory. Dr. Jacobsen relies on G.993.1 for its “initialization message scheme.” See Jacobsen Report at ¶ 595.

344. Dr. Jacobsen asserts that a reason to combine Mazzoni and G.993.1 is that both are “directed to VDSL and to VDSL transceivers.” See Jacobsen Report at ¶ 592. This in and of itself, or in combination with any other argument made by Dr. Jacobsen in Section VIII.F.4 of the Jacobsen Report, is not sufficient show that a person of ordinary skill in the art would have combined the teachings of the two references. At the time of the invention of the Family 3 Patents, the VDSL standard was still under development and there were likely hundreds of references directed to possible implementation details of many and varied proposals for VDSL transceivers. One of skill in the art at the time would have understood that many of these references would be completely incompatible with one another and/or, if combined, would provide no useful benefit. Thus, that Mazzoni and G.993.1 are both directed to different proposals for developing VDSL transceivers, would not have made their combination obvious.

345. Dr. Jacobsen then states that “each of Mazzoni and G.993.1 discloses a need to allocate memory for interleaving and deinterleaving.” See Jacobsen Report at ¶ 593. This in and of itself, or in combination with any other argument made by Dr. Jacobsen in Section VIII.F.4 of the Jacobsen Report, is again not sufficient to motivate a person of ordinary skill in the art to combine the teaching of the two references. It is far too general of a concept to provide any motivation to combine one reference with the



other. In fact, it is not materially different than saying that Mazzoni and G.993.1 contemplate the use of memories for interleaving and deinterleaving.

346. Dr. Jacobsen states that: “[a]s a person having ordinary skill in the art as of the ‘473 patent’s priority date would have understood, Mazzoni’s table is limiting in that all of the services would have to be identified ahead of time and stored in the transceivers. One of ordinary skill in the art would have recognized that conveying interleaver parameters through initialization message scheme of G.993.1 would avoid this limitation of Mazzoni’s table and would result in a more flexible solution.” *See Jacobsen Report at ¶ 595.* This is incorrect.

347. A POSITA would not look to add a message (from G.993.1 or otherwise) to the system disclosed in Mazzoni, and in fact doing so would provide no useful benefit. This is because the system disclosed in Mazzoni relies on the use of a pre-populated table of I, M, I’, and M’ parameter values, where each set of values corresponds to a respective one of a number of predetermined data rate service pairs. *See Mazzoni at 5:22-23, 5:27-30, 6:51-55.* There is no use for a message that specifies the maximum supported interleaver or deinterleaver memory size because all data rate pairs and their corresponding I, M, I’, and M’ values that need to be supported are accounted for. Mazzoni contemplates TO and TU transceiver pairs that will both be preconfigured at the time of installation with the same predetermined parameters selected from a limited number of possibilities. Thus, exchanging messages describing the capabilities of the transceivers would be redundant and serve no useful purpose.

348. “Flexibility” is also too generic of a motivation to combine and, in any event, Mazzoni provides substantial flexibility already given that it allows 12 difference service configurations. One of skill in the art who perceived the benefits of the simplicity of configuration that Mazzoni provides would not be motivated to use the complex messaging and initialization scheme of G.993.1.

349. An additional reason why G.993.1’s exchange of maximum supported memory sizes would not be recognized as beneficial to Mazzoni is that it is incompatible. For example, per G.993.1, the VTU-R (i.e., TU of Mazzoni) transmits to the VTU-O (i.e., TO of Mazzoni) an R-MSG2 message that specifies the maximum downstream deinterleaver memory size that it supports. Then the VTU-O transmits to the VTU-R an O-MSG2 message that specifies the maximum upstream interleaver memory size it can support. Using the predefined services described in Mazzoni, i.e., S1-S6 and A1-A6 (*see* Mazzoni at 3:62 – 4:14), the maximum downstream deinterleaver memory that Mazzoni is capable of supporting is determined by reference to the A6 service and the maximum upstream interleaver memory that Mazzoni is capable of supporting is determined by reference to the S6 service. The A6 service provides a downstream bit rate of 832x64 kbit/s and requires 24,960 bytes of deinterleaver memory. *See id.* at 6:11-30 (describing calculation of required deinterleaver memory size). The S6 service provides an upstream bit rate of 362x64 kbit/s. Per the calculations described at 6:11-30 of Mazzoni, the S6 service requires that the VTU-R be capable of supporting a maximum upstream interleaver memory of 10,860 bytes. If the Mazzoni VTU-O received a message indicating that the VTU-R supported a maximum

downstream deinterleaver memory of 24,960 bytes and a maximum upstream interleaver memory of 10,860 bytes (based on the maximum interleaver delay), this information would be useless to the VTU-O. First, it already has the information necessary to support the service for which both transceivers have been preconfigured at the time of installation. Second, neither the VTU-O or VTU-R would actually be capable of simultaneously supporting both maximum interleaver and deinterleaver sizes at the same time because the total memory size of the Mazzoni transceivers is only 26,890 bytes (as determined by the combined upstream and downstream bit rates of the A6 service). *See id.* at 4:18-22 and 6:45-50.

350. Further, while Dr. Jacobsen does not put forth any argument regarding any other messages in her report (I reserve the right to respond to any such new argument to the extent she is allowed to raise it), per G.993.1, after the exchange of the R-MSG2 and the O-MSG2 messages, the VTU-R transmits an R-CONTRACT1 message to the VTU-O including a “proposed downstream contract.” Subsequently, the VTU-O transmits the O-CINTRACT1 message to the VTU-R which contains a proposed upstream contract and a downstream contract, where the downstream contract is based on the R-CONTRACT1. Again, Mazzoni already has the information necessary to support the service for which both transceivers have been preconfigured at the time of installation and does not need to rely on messages to convey the redundant information.

351. A POSITA at the time of the Family 3 Patent inventions would not combine the teachings of Mazzoni with the teachings of G.993.1. In fact, a POSITA would be discouraged from doing so. Because Mazzoni teaches that an assignment of the memory is performed at the time of the installation of the modem based on a table, and not a message, adding a message (or multiple messages) to this system per G.993.1 would be unnecessary, redundant, and create useless complexity during initialization. Further, because Mazzoni is concerned with supporting a finite set of predefined service configurations (i.e., data rate pairs and corresponding interleaver/deinterleaver parameter values).

352. For at least the foregoing reasons, Dr. Jacobsen has not demonstrated that a POSITA would have been motivated to combine G.993.1 with Mazzoni in the manner she proposes.

**2. The Combination of Mazzoni and G.993.1 Does Not Render Claim 19 of the '473 Patent Obvious**

353. It is my opinion for the reasons provided in Section VI.F.1 above and as further discussed in this Section VI.F.2, that a POSITA would not combine Mazzoni and G.993.1 or arrive at the claimed invention even if one were to attempt to combine these references in some way. It is further my opinion and conclusion that Mazzoni in combination with G.993.1 fails to disclose each element of claim 19 of the '473 patent, and hence fails to render claim 19 of the '473 patent obvious as described in detail, below.

- a. **The Combination of Mazzoni and G.993.1 does not disclose a multicarrier transceiver being associated with a memory wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.**

354. Mazzoni in combination with G.993.1 does not disclose this limitation. Dr. Jacobsen incorporates by reference her arguments with respect to Mazzoni by pointing to Section IX.B.6.e of the Jacobsen Report. These arguments have been addressed in Section VI.B.6.a, *supra* and further below.

355. Dr. Jacobsen then points to Section IX.C.6.e of the Jacobsen Report for support that “G.993.1 teaches sending messages during initialization that indicate maximum interleaver delay, as well as ways of allocating memory between an interleaver and a deinterleaver.” Dr. Jacobsen does not explain which of her arguments in the cited section are applicable to this new combination. Nor does Dr. Jacobsen address the “ways of allocating memory between an interleaver and a deinterleaver” in G.993.1 in this or the cited section. I reserve the right to address any support or explanation Dr. Jacobsen’s attempts to provide for her currently conclusory assertions regarding this combination of references.

356. Nonetheless, looking back at the cited Section IX.C.6.c from the Jacobsen Report, Dr. Jacobsen describes the R-MSG2 and the O-MSG2 messages in paragraphs 447-448. As I explained in Section VI.F.1, *supra*, G.993.1’s exchange of interleaver and deinterleaver capabilities though those messages is redundant to Mazzoni’s stored predefined service data rates and interleaver/deinterleaver parameters and incompatible with Mazzoni at least because the exchange of maximum supported

interleaver and deinterleaver sizes per G.993.1 would specify a combined amount of interleaver and deinterleaver memory that would exceed Mazzoni's total memory size.

357. Further with respect to Mazzoni, looking back at what Dr. Jacobsen incorporates by reference, contrary to her opinion, Mazzoni does not disclose exchanging any messages at all that includes information about interleaving or deinterleaving parameters (or any other information upon which interleaver or deinterleaver memory allocations could be based). Dr. Jacobsen asserts that "[o]ne of ordinary skill in the art would have understood that this information, as well as capabilities of the transceiver at the other end of the system, would have to be conveyed, for example, in the form of a message during initialization, and that the memory would be allocated between the interleaving function and the deinterleaving function in accordance with that message." Jacobsen Report at ¶ 339. The "information" she is referring to is the parameters  $I$ ,  $M$ ,  $I'$  and  $M'$ . But, she cannot point to any disclosure of such a message in Mazzoni because there is no such disclosure. Instead, it seems that she is interpreting Mazzoni's description of the configurability of its interleaver means and deinterleaver means according to upstream and downstream bit rates as somehow disclosing reliance on an exchange of  $I$ ,  $M$ ,  $I'$  and  $M'$ . *See id.* (citing Mazzoni at 1:61-65 and 5:24-31). But parameters  $I$ ,  $M$ ,  $I'$  and  $M'$  are not exchanged in any message; rather, as discussed above in Section VI.B.1, *supra*, these parameters are stored in a table in each transceiver and indexed to a predefined service that includes predefined upstream and downstream bit rates. Mazzoni at 6:53-61. The parameter values for the particular predefined service are retrieved by the control means MCD at

the time the modem is installed (*id.*) and delivered by the MCD to the interleaver means MET and deinterleaver means MDET (*id.* at 5:21-23 and Fig. 3). This eliminates any need to exchange these parameters between modems.

358. One of the passages Dr. Jacobsen cites for this assertion (again in the section incorporated by reference), Mazzoni at column 5:24-31, does not describe some alternative embodiment where the I, M, I' and M' parameters are exchanged in messages. Rather, this passage simply describes the use of the predetermined parameters that are indexed to the predetermined service bit rates the transceiver has been configured to use. Dr. Jacobsen accurately admits this in her report when addressing the purported motivation to combine Mazzoni and G.993.1. *See, e.g.,* Jacobsen Report at ¶ 595 (“Mazzoni discloses keeping a table of values of the interleaver parameters, indexed by service identifiers, in the transceiver. *See id.* at col. 6:51-61. As a person having ordinary skill in the art as of the '473 patent's priority date would have understood, Mazzoni's table is limiting in that all of the services would have to be identified ahead of time and stored in the transceivers.”); *see also id.* at ¶ 626.

359. The other passage Dr. Jacobsen relies on for this assertion, Mazzoni at column 1:61-65, also does not disclose or require the exchange of any interleaver or deinterleaver parameters in a message. To the extent Dr. Jacobsen is interpreting this passage as disclosing anything other than the use of predetermined parameters that correspond to predetermined bit rates, she has misunderstood Mazzoni. In fact, the sentence after the one she quotes shows that the reference to “the bit rate actually processed by the send/receive device (modem)” is referring to one of the

predetermined bit rates for a predetermined service. Mazonni at 1:65 – 2:2 (“The invention therefore provides a device for sending/receiving digital data that is capable of *processing different bit rates from a group of predetermined bit rates* (e.g., all the symmetrical or asymmetrical services offered by the VDSL communication system).”). Therefore, Mazzoni does not, and need not, rely on any messages to carry out its suggested implementation. In fact, a POSITA would be discouraged to look to any references disclosing messages as described above.

360. Accordingly, the combination of G.993.1 and Mazzoni does not disclose “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver” and, at least for this reason, claim 19 of the ‘473 patent is not obvious in view of LB-031 and Mazzoni.

- b. The combination of Mazzoni and G.993.1 does not disclose a multicarrier transceiver being associated with a memory wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.**

361. For the reasons discussed immediately above and in Sections VI.F.1 and VI.B.6.b, *supra*, Mazzoni does not disclose this claim element.

362. Dr. Jacobsen incorporates her arguments regarding Mazzoni from “Section (sic paragraph) 339.” Yet, this paragraph does not address what Dr. Jacobsen asserts it does. Nonetheless, Dr. Jacobsen’s arguments from this paragraph have been addressed in Section VI.B.6.a, *supra*. I also incorporate my arguments regarding Mazzoni from Section VI.B.6.b, *supra*. In summary, as I explained in the section



immediately above, Mazzoni does not disclose exchanging any messages at all that include information about interleaving or deinterleaving parameters (or any other information upon which interleaver or deinterleaver memory allocations could be based). Further, as I explained in the section immediately above and in Section VI.F.1, *supra*, G.993.1's exchange of interleaver and deinterleaver capabilities is redundant to and incompatible with Mazzoni.

363. With respect to G.993.1, Dr. Jacobsen cites to Section IX.C.6.f. Dr. Jacobsen's conclusion in paragraph 452 of that section of the Jacobsen Report states that "[o]ne of ordinary skill in the art would have understood that data would need to be interleaved and deinterleaved at the same time in this mode of transmission, which would require that a portion of the memory be allocated to an interleaving function, and a portion of the memory would be allocated to a deinterleaving function." This is incorrect. That an interleaver and deinterleaver operate at the same time does not disclose or require that a portion of the memory be allocated to the interleaver function or deinterleaver function at any one particular time depending on the message. Perhaps this was a cut and paste error and was intended for the element of claim 5 of the '381 patent, which recites: "wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver."

364. For at least the foregoing reasons, the combination of Mazzoni and G.993.1 does not disclose "a multicarrier transceiver being associated with a memory wherein at least a portion of the memory may be allocated to the interleaving function or the

deinterleaving function at any one particular time depending on the message” and, at least for this reason, claim 19 of the ‘473 patent is not obvious in view of Mazzoni and G.993.1.

**G. Claim 19 of the ‘473 Patent Is Not Obvious Over Voith and G.993.1, or, In the Alternative, In View of Voith, G.993.1 and Mazzoni**

365. It is my opinion and conclusion that Voith alone or in combination with G.993.1 fails to disclose or suggest each element of claim 19 of the ‘473 patent, and hence fails to render claim 19 of the ‘473 patent obvious as described in detail, below.

366. It is also my opinion that regardless of the disclosures of Voith and G.993.1 individually, a person of ordinary skill in the art would not be motivated to combine the teachings of Voith with the teachings of G.993.1 at least for the reasons described in Section VI.F.3, *supra*.

**1. Neither Voith nor G.993.1 discloses a multicarrier communications transceiver associated with a memory “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver”**

367. Voith does not disclose this limitation as discussed in section VI.E.1, *supra*.

368. Dr. Jacobsen refers to Section IX.C.6.e of the Jacobsen Report and contends that “G.993.1 teaches sending messages during initialization that indicate maximum interleaver delay, as well as ways of allocating memory between an interleaver and a deinterleaver.” Jacobsen Report at ¶ 611. As an initial matter, Dr. Jacobsen has provided no evidence for her assertion that the G.993.1 standard teaches “allocating memory between an interleaver and a deinterleaver” much less “allocating memory between an interleaver and a deinterleaver in accordance with a message received

during an initialization” based on a message received during initialization. Rather, a POSITA would understand G.993.1 to provide for dedicated downstream memories in each transceiver and separate, dedicated upstream memories in each transceiver. The use of such dedicated memories is consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems, including the LB-031 modem. *See* §§ IV and VI.A.5.a.ii, *supra*. As explained in these cited sections above, portions of dedicated interleaver memory that are not needed for interleaving cannot be allocated for use by the deinterleaver, and vice versa. Instead, those portions simply go unused. *Id.*

369. Assuming for the sake of argument that the G.993.1 message identified by Dr. Jacobsen indicates a “maximum interleaver delay,” nothing in the G.993.1 standard suggests “allocating memory between an interleaver and a deinterleaver in accordance,” with the “maximum interleaver delay.” Again, given the state of DSL transceivers during the relevant time frame and the maximum data rates specified by the G.993.1, there is no basis for assuming that DSL transceivers implementing G.993.1 would have used anything other than dedicated, separate interleaver and deinterleaver memories. A POSITA would have understood that the interleaver of a G.993.1-complaint transceiver may have used less than all of its dedicated interleaver memory based on the memory capabilities of the far-end transceiver’s deinterleaving function. However, the transceiver would not have been capable of reallocating the unused interleaver memory to its deinterleaver.

370. At least for these reasons, Voith and G.993.1 do not teach a transceiver “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.”

2. **Neither Voith nor G.993.1 discloses a multicarrier communications transceiver associated with a memory “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message”**

371. Voith does not disclose this limitation as discussed in section VI.E.2, *supra*.

372. With reference to G.993.1, for the same reasons set forth above at § VI.C.5.b, my opinion is that G.993.1 does not disclose this limitation. Additionally, as discussed in the section immediately above, there is no basis for assuming that DSL transceivers implementing G.993.1 would have used anything other than dedicated, separate interleaver and deinterleaver memories. Rather, a POSITA would have understood that the interleaver of a G.993.1-complaint transceiver may have used less than all of its dedicated interleaver memory but the transceiver would not have been capable of reallocating the unused interleaver memory to its deinterleaver. Thus, no portion of any memory could be allocated to an interleaving function at one time and to a deinterleaving function at another time.

373. At least for these reasons, Voith and G.993.1 do not teach a transceiver “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.”

### 3. No Motivation to Combine Voith with G.993.1

374. For the following reasons, I disagree with Dr. Jacobsen's assertion at paragraphs 566-568 of the Jacobsen Report that "one of ordinary skill in the art would have been motivated to combine Voith and G.993.1."

375. First, Dr. Jacobsen asserts that that there is a motivation to combine because both references are in the DSL field. *See* Jacobsen Report at ¶ 617. This in and of itself, or in combination with any other argument made by Dr. Jacobsen in Section IX.G.3 of the Jacobsen Report, is not sufficient to show that a person of ordinary skill in the art would have combined the teachings of the two references. At the time of the invention of the Family 3 Patents, the DSL standards have been under continuous development and there were likely hundreds, if not thousands, of references directed to possible implementation details of many and varied proposals for DSL transceivers. One of skill in the art at the time would have understood that many of these references would be completely incompatible with one another and/or, if combined, would provide no useful benefit. Thus, that Voith and G.993.1 are purportedly both directed to different proposals for DSL transceivers, would not have made their combination obvious.

376. Dr. Jacobsen further asserts that there is a motivation to combine because each of the references purportedly "discloses a need to allocate memory for interleaving and deinterleaving." *Id.* at ¶ 617. This in and of itself, or in combination with any other argument made by Dr. Jacobsen in Section IX.G.3 of the Jacobsen Report, is not sufficient to motivate a person of ordinary skill in the art to combine the teaching of the

two references. It is far too general of a concept to provide any motivation to combine one reference with the other. In fact, it is not materially different than saying that Voith and G.993.1 contemplate the use of memories for interleaving and deinterleaving.

377. I also disagree with Dr. Jacobsen's assertion that there is a motivation to combine Voith and G.993.1 because they purportedly both relate to "allocating memory for interleaving and deinterleaving to support various applications." Jacobsen Report at ¶ 618.

378. With reference to Voith, Dr. Jacobsen asserts that Voith's recognition that "ADSL transceiver 34 requires a large amount of memory, which is preferably implemented off-chip in external interleave/de-interleave memory 66" somehow means that Voith "discloses a need to allocate memory for interleaving and deinterleaving." Jacobsen Report at ¶ 617. I disagree with this assertion. Voith merely teaches that it is preferable to implement the memory buffers off-chip, because "large buffers consume a large integrated circuit area which adds to cost." Voith at 2:27-28. Thus, Voith's fundamental premise is to concede that the memory buffers are required to be large but Voith makes no proposal for reducing such requirement. Voith certainly does not propose the use of sharing memory for interleaving and deinterleaving where a portion of the memory can be used at one time for interleaving and at another time for deinterleaving as explained immediately above sections VI.E.1 and 2.

379. With reference to the G.993.1 standard, Dr. Jacobsen asserts that "[o]ne of ordinary skill in the art would therefore have recognized that the teachings of G.993.1 show a reliable and efficient way of enabling the transceivers of Voith to partition the

shared memory between the interleaver and deinterleaver.” Jacobsen Report at ¶ 619. I disagree, there is no disclosure or suggestion in G.993.1 of using or partitioning shared memory. Dr. Jacobsen does not cite any portion of G.993.1 as purportedly disclosing this. On the contrary, a POSITA would understand G.993.1 to provide for dedicated downstream memories in each transceiver and separate, dedicated upstream memories in each transceiver. The use of such dedicated memories is consistent with other DSL modems of that era and proposals for VDSL modems, including the LB-031 modem. *See* §§ IV and VI.A.5.a.ii, *supra*. As explained in these cited sections above, portions of dedicated interleaver memory that are not needed for interleaving cannot be allocated for use by the deinterleaver, and vice versa. Instead, those portions simply go unused. *Id.*

380. Therefore, it is my opinion that a POSITA would not have been motivated to combine Voith and G.993.1 in the manner proposed by Dr. Jacobsen, and Dr. Jacobsen has not shown otherwise.

#### **4. Mazzoni does not Supply the Disclosure Missing from G.993.1 and Voith**

381. Dr. Jacobsen contends that “Mazzoni discloses that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.” Jacobsen Report at ¶ 623. Contrary to Dr. Jacobsen’s opinion, Mazzoni does not disclose exchanging any messages at all that include information about interleaving or deinterleaving parameters (or any other information upon which interleaver or deinterleaver memory

allocations could be based). I incorporate by reference my opinions set forth at §§ VI.B.6.a and VI.B.6.b for why Mazzoni does not disclose this element of the claim.

**5. A POSITA would not be Motivated to Combine Mazzoni with Voith and G.993.1**

382. Contrary to Dr. Jacobsen's assertion, a POSITA would not be motivated to combine Mazzoni with Voith and G.993.1. First, Dr. Jacobsen asserts that there is a motivation to combine because these references are "in the DSL field." Jacobsen Report at ¶ 625. This in and of itself, or in combination with any other argument made by Dr. Jacobsen in Section IX.G.5 of the Jacobsen Report, is not sufficient to show that a person of ordinary skill in the art would have combined the teachings of the three references. At the time of the invention of the Family 3 Patents, the DSL standards have been under continuous development and there were likely hundreds, if not thousands, of references directed to possible implementation details of many and varied proposals for DSL transceivers. One of skill in the art at the time would have understood that many of these references would be completely incompatible with one another and/or, if combined, would provide no useful benefit. Thus, that Mazzoni, Voith and G.993.1 are purportedly both directed to different proposals for DSL transceivers, would not have made their combination obvious.

383. Dr. Jacobsen also contends that "[l]ike Voith and G.993.1, Mazzoni describes a need to allocate memory for interleaving and deinterleaving." See Jacobsen Report at ¶ 625. This in and of itself, or in combination with any other argument made by Dr. Jacobsen in Section IX.G.5 of the Jacobsen Report, is again not sufficient to



motivate a person of ordinary skill in the art to combine the teaching of the three references. It is far too general of a concept to provide any motivation to combine one reference with the other. In fact, it is not materially different than saying that Mazzoni, Voith and G.993.1 contemplate the use of memories for interleaving and deinterleaving.

384. I also disagree with Dr. Jacobsen assertion that “Voith discloses that efficiency in the use of memory is desirable.” On this point, I disagree with Dr. Jacobsen for the reasons set forth at ¶ 379 *supra*.

385. With reference to the G.993.1 standard, Dr. Jacobsen asserts that “G.993.1 discloses how memory is allocated in accordance with a message received during initialization” and that “[o]ne of ordinary skill in the art would therefore have recognized that the teachings of G.993.1 show a reliable and efficient way of enabling the transceivers of Mazzoni to partition the shared memory between the interleaver and deinterleaver without requiring all of the possible services to be defined in advance to create the table disclosed in Mazzoni.” Jacobsen Report at ¶ 627. I disagree, there is no disclosure or suggestion in G.993.1 of using or partitioning shared memory. Dr. Jacobsen does not cite any portion of G.993.1 as purportedly disclosing this. On the contrary, a POSITA would understand G.993.1 to provide for dedicated downstream memories in each transceiver and separate, dedicated upstream memories in each transceiver. The use of such dedicated memories is consistent with other DSL modems of that era and proposals for VDSL modems, including the LB-031 modem. *See* §§ IV and VI.A.5.a.ii, *supra*. As explained in these cited sections above, portions of dedicated

interleaver memory that are not needed for interleaving cannot be allocated for use by the deinterleaver, and vice versa. Instead, those portions simply go unused. *Id.*

386. Further, a POSITA would not look to add messages (from G.993.1 or otherwise) to the system disclosed in Mazzoni, and in fact doing so would provide no useful benefit. It would certainly not be any more reliable and efficient than Mazzoni's existing scheme. This is because the system disclosed in Mazzoni relies on the use of a pre-populated table of I, M, I', and M' parameter values, where each set of values corresponds to a respective one of a number of predetermined data rate service pairs. See Mazzoni at 5:22-23, 5:27-30, 6:51-55. There is no use for a message that specifies the interleaver or deinterleaver memory sizes because all data rate pairs and their corresponding I, M, I', and M' values that need to be supported are accounted for. Mazzoni contemplates TO and TU transceiver pairs that will both be efficiently and reliably preconfigured at the time of installation with the same predetermined parameters selected from a limited number of possibilities. Thus, exchanging messages describing the capabilities of the transceivers would be redundant, serve no useful purpose, and make the system less reliable and efficient.

387. Therefore, it is my opinion that a POSITA would not have been motivated to combine Mazzoni with Voith and G.993.1 in the manner proposed by Dr. Jacobsen, and Dr. Jacobsen has not shown otherwise.

## **VII. CONCLUSION**

388. For the foregoing reasons, it is my opinion that the Asserted Claims of the Family 3 Patents are valid and are neither anticipated nor obvious in view of the prior art and the knowledge of a person of ordinary skill in the art.

# **EXHIBIT 12**

**IN THE UNITED STATES DISTRICT COURT  
FOR THE DISTRICT OF DELAWARE**

TQ DELTA, LLC,

Plaintiff,

v.

2WIRE, INC.

Defendant.

Civil Action No. 13-cv-1835-RGA

**REPLY EXPERT REPORT OF DR. KRISTA S. JACOBSEN FOR FAMILY 3  
PATENTS**

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**I. INTRODUCTION**

1. My name is Dr. Krista S. Jacobsen. I provide this report in reply to the Corrected Rebuttal Expert Report of Dr. Todor Cooklev Regarding Validity of the Family 3 Patents (“Cooklev Report”), served originally on December 28, 2018, with the corrected version served on January 4, 2019. The Cooklev Report was submitted in response to my Opening Expert Report for Family 3 Patents (my “Opening Report” or “Jacobsen Opening Report”) in the above-captioned action.

2. Between now and any time that I may be asked to testify at trial, I expect to continue my review, evaluation, and analysis of information generated during discovery, as well as evidence that either side presents before or at trial. I further reserve the right to amend or supplement this report, as appropriate, after considering opinions set forth in Plaintiff’s expert reports, and/or if additional relevant information becomes available to me. I reserve the right to supplement this report as necessary.

3. That I do not specifically disagree with a portion of Dr. Cooklev’s report does not mean that I agree with that portion.

**II. APPLICABLE LEGAL PRINCIPLES**

4. I have reviewed Dr. Cooklev’s summary of the applicable legal principles.

5. At paragraph 25, Dr. Cooklev asserts that “there must be some teaching or suggestion in the references to support their use in the particular claimed combination.” This statement does not comport with my understanding of the law on the use of combinations of references to show that a claimed invention would have been obvious to a person having ordinary skill in the art. I set forth my understanding in paragraph 21 of my Opening Report, which stated (emphasis added):

I am informed and understand that an obviousness evaluation can be made using either a single reference or a combination of several prior art references. An obviousness analysis involving two or more references generally requires a reason why a person having ordinary skill in the relevant field would have combined aspects of those references in the way the asserted patent claims do. I understand that the prior art references themselves may provide a suggestion, motivation, or reason to combine, but other times the link may simply be common sense. An obviousness analysis can recognize that market demand, rather than scientific literature, often drives innovation, and that is sufficient motivation to combine references.

Thus, I disagree with Dr. Cooklev's statement that "there must be some teaching or suggestion in the references to support their use in the particular claimed combination." Cooklev Report at ¶ 25. It is my understanding that a teaching or suggestion in the references is only one potential source of the motivation to combine references.

6. Dr. Cooklev states that he is "informed that a reference patent is entitled to claim the benefit of the filing date of its provisional application if the disclosure of the provisional application provides support for the claims in the reference patent." Cooklev Report at ¶ 39. It is my understanding that there are other conditions (e.g., common inventorship) required for a later-filed application to claim the benefit of an earlier-filed provisional application.

### **III. LEVEL OF SKILL IN THE ART**

7. I incorporate by reference the reference the Level of Skill in the Art section from my Rebuttal Expert Report of Dr. Krista S. Jacobsen for Family 3 Patents (my "Rebuttal Report" or "Jacobsen Rebuttal Report") (see Section VI, ¶¶ 15-19), which includes my response to Dr. Cooklev's characterization of the level of skill in the art.

#### IV. BACKGROUND OF THE TECHNOLOGY

8. I incorporate by reference the Background of the Technology section from my Rebuttal Report (*see* Section VII, ¶¶ 20-44), which includes my response to Dr. Cooklev’s characterization of the background of the technology.

9. Dr. Cooklev states, incorrectly, that “DSL systems, such as, for example, ADSL2/2+ standards known at the time of the inventions, specify dedicated interleaving memory requirements in each transceiver separately for upstream and downstream transmission (i.e., in each direction separately).” Cooklev Report at ¶ 42. I disagree. First, none of the ADSL2/2+ standards specifies the use of dedicated memory for interleaving or deinterleaving. In fact, the versions of ADSL2/2+ in existence as of the priority date of the Family 3 patents<sup>1</sup> do not even use the word “memory.” *See, e.g.*, G.992.3 (07/2002); G.992.3 (01/2005); G.992.5 (05/2003); G.992.5 (01/2005). The ADSL2/2+ standards do not specify or require any particular memory configuration for interleaving or deinterleaving, much less “dedicated interleaving memory requirements.”

10. Second, the ADSL2/2+ standards specify interleaving delay requirements, not memory requirements. *See, e.g.*, G.992.3 (07/2002) at § 7.7.1.5 (“Each of the  $N_{FEC,p}$  octets  $B_0, B_1, \dots, B_{N_{FEC,p}-1}$  in an FEC Output Data Frame is delayed by an amount that varies linearly with the octet index. More precisely, octet  $B_i$  (with index  $i$ ) is delayed by  $(D_p - 1) \times i$  octets, where  $D_p$  is the interleaver depth.”); G.992.3 (01/2005) at § 7.7.1.5 (same).

11. For at least these reasons, I disagree with Dr. Cooklev’s statement that “an ADSL2/2+ ATU-C is required to have a specified amount of dedicated interleaving memory for

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<sup>1</sup> I explained in my Opening Report why, in my opinion, the asserted claims of the Family 3 patents are not entitled to the benefit of the ’269 provisional application filed on October 12, 2004, and that the priority date is the filing date of the ’890 patent, October 11, 2005. My opinions, however, are the same regardless of whether the filing date is October 12, 2004 or October 11, 2005.

downstream data transmission and separately and independently have a specified amount of dedicated interleaving memory for upstream data reception.” Cooklev Report at ¶ 42.

Although, as I explained in my Rebuttal Report, an interleaving delay requirement establishes a minimum amount of memory required in each of the transmitter and receiver to meet that delay, ADSL2/2+ does not require the use of dedicated interleaving memory and dedicated deinterleaving memory. Therefore, I also disagree with Dr. Cooklev’s statements in paragraph 42 that “the ATU-C must have . . . 16,320 octets of dedicated interleaving memory for downstream . . . [and] 2,048 octets of dedicated deinterleaving memory for upstream.”

12. For the same reasons, I disagree with Dr. Cooklev’s statement that “an ADSL2/2+ ATU-R is required to have a specific amount of dedicated interleaving memory for downstream data reception and separately have a specific amount of dedicated interleaving memory for upstream data transmission.” Cooklev Report at ¶ 43. And I also disagree that “the ATU-R must have . . . 16,320 octets of dedicated deinterleaving memory for downstream . . . [and] 2,048 octets of dedicated interleaving memory [for interleaving].” *Id.* As I stated above, the ATU-R must have memory for interleaving and deinterleaving, but the standards do not require dedicated memory.

13. Without any support, Dr. Cooklev contends that “[t]he ADSL2/2+ standards do not specify or enable memory sharing between the interleaver and the deinterleaver in a single transceiver.” Cooklev Report at ¶ 44. Although the ADSL2/2+ standards do not require memory sharing, I disagree with the implication that they specify the use of dedicated memory. As I explained above, the standards do not specify any particular memory implementation. Furthermore, I disagree with Dr. Cooklev’s assertion that the ADSL2/2+ standards do not “enable memory sharing between the interleaver and the deinterleaver in a single transceiver.”

Whether a transceiver uses shared memory is an implementation choice, and nothing in ADSL2/2+ would prohibit a transceiver from using shared memory for interleaving and deinterleaving.

14. I also disagree with Dr. Cooklev's statement that "ADSL2/2+ specify that the ATU-C downstream interleaver and the ATU-R downstream deinterleaver have the same amount of memory (i.e., ~16K octets) . . . [and] the ATU-R upstream interleaver and the ATU-C upstream deinterleaver have the same amount of memory (i.e. ~2K octets)." Cooklev Report at ¶ 44. As I explained above, ADSL2/2+ do not specify amounts of memory; they specify interleaving delay. As I explained in my Rebuttal Report (*see, e.g.* Jacobsen Rebuttal Report at § IX), the amount of memory an implementation uses to meet a specified interleaving delay (whether performing the interleaving operation or the deinterleaving operation) can be any amount greater than or equal to  $(D - 1) \times (I - 1) / 2$ , where D is interleaver depth and I is interleaver block size.

15. I also disagree with Dr. Cooklev's assertion that "[p]rior to the inventions disclosed in the Family 3 patents, an amount of memory available to an interleaver was predetermined and an amount of memory available to a deinterleaver was predetermined." Cooklev Report at ¶ 45. As I have explained, the ADSL2/2+ standards do not specify the amounts of memory available to an interleaver or a deinterleaver.

16. Dr. Cooklev concludes his discussion of "Interleaver Memory and Deinterleaver Memory in Prior Art Systems" with the assertion that prior-art systems "were incapable of sharing memory between an interleaving and deinterleaving function based on a message." Cooklev Report at ¶ 45. Dr. Cooklev has provided no support for this assertion and does not purport to have determined how prior-art transceivers, or even just prior-art ADSL2/2+

transceivers, implemented interleaving and deinterleaving, whether by using messages or through some other means. His conclusion that prior-art systems “were incapable of sharing memory between an interleaving and deinterleaving function based on a message” is unsupported and, in my opinion, amounts to pure speculation.

17. In paragraphs 46 through 57, Dr. Cooklev continues to speculate as to how existing transceivers provided interleaving and deinterleaving functions as of the priority date of the Family 3 patents. Specifically, he purports to compare how “the interleaver memory and the deinterleaver memory in a single transceiver had been implemented in prior art systems before the inventions of the Family 3 patents . . . with how the shared memory can be allocated to an interleaver and a deinterleaver according to the inventions of the Family 3 patents.” Cooklev Report at ¶ 46. Again, Dr. Cooklev provides no support for his statements regarding how prior-art transceivers implemented interleaving and deinterleaving. For example, despite having worked for Aware from 2000 to 2002, Dr. Cooklev has not even stated whether Aware’s transceivers<sup>2</sup> operated as he contends, *i.e.*, using dedicated interleaving memory and dedicated deinterleaving memory. Furthermore, he has not represented that he has determined how other existing prior-art transceivers, whether for DSL or other applications, provided memory for interleaving and deinterleaving, much less that they did not use shared memory. In my opinion, there is no basis whatsoever for Dr. Cooklev’s conclusion that prior-art transceivers did not use shared memory for interleaving and deinterleaving. Indeed, several of the prior-art references I applied in my Opening Report and discuss further below suggest just the opposite.

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<sup>2</sup> As of 2001, Aware offered for sale at least one transceiver, the AW-918 ADSL Transceiver Module. *See, e.g.*, <https://web.archive.org/web/20010218175422/http://www.aware.com:80/products/Hardware/modules.html> (last visited January 6, 2019).

18. Dr. Cooklev's examples at paragraphs 47-57 find no support in the Family 3 patents or their file histories. Moreover, through this example, Dr. Cooklev appears to suggest that the use of shared memory for interleaving and deinterleaving was introduced by the Family 3 patents. It was not. As I explained in my Rebuttal Report (*see, e.g.*, § VII.D), the Family 3 patents did not introduce the idea of sharing memory between an interleaver and deinterleaver, either generally or for DSL transceivers in particular. Multiple prior-art references (*e.g.*, Fadavi-Ardekani, Mazzoni, Voith, *etc.*) described the use of shared memory for interleaving and deinterleaving in DSL transceivers. The Family 3 Patents describe specific ways of allocating shared memory using information contained in an initialization message that specifies a maximum amount of memory available to be allocated to an interleaver or deinterleaver; they do not claim merely sharing memory between an interleaver and a deinterleaver. Indeed, the examiners of various Family 3 patents' applications specifically noted that sharing memory between an interleaver and deinterleaver was known in the prior art. *See, e.g.*, 10/06/2010 Notice of Allowance and Fees Due from '882 patent's file history (TQD004331) ("The closest prior art, Fadavi-Ardekani et al (U.S. Pat. No. 6,707,822) discloses sharing a memory between the interleavers and deinterleavers of multiple ADSL sessions. . . ."). Therefore, to the extent Dr. Cooklev's examples at paragraphs 47-57 suggest that there is some benefit to using shared memory for interleaving and deinterleaving, that benefit is not due to any contribution of the Family 3 patents.

19. Dr. Cooklev mischaracterizes my opinion in paragraph 58 of his report. Specifically, Dr. Cooklev states that "Dr. Jacobsen asserts that prior art systems were capable of providing 'shared memory that the transceiver can partition between its interleaver and deinterleaver on a per-connection basis.'" Cooklev Report at ¶ 58. He then proceeds to

summarize or quote selected portions of the prior-art references I applied in my Opening Report and concludes that none of them discloses “shared memory that can be partitioned between its interleaver and deinterleaver on a per-connection basis.” *See, e.g.*, Cooklev Report at ¶¶ 60, 61, 62, 63, 64. As an initial matter, “shared memory that can be partitioned between its interleaver and deinterleaver on a per-connection basis” is not a limitation of any asserted Family 3 claim, nor is it required by the Court’s claim construction. According to the Court’s claim construction, “shared memory” is merely “common memory used by at least two functions, where a portion of the memory can be used by either one of the functions.” The Court’s construction does not require partitioning at all, much less between an interleaving function and a deinterleaving function on a per-connection basis. Indeed, the Court’s construction does not even mention interleaving/interleavers or deinterleaving/deinterleavers.

20. In addition, I did not assert that each of the prior-art references discloses “shared memory that can be partitioned between its interleaver and deinterleaver on a per-connection basis.” In fact, my Opening Report states, in the discussion of the technology background:

There are two ways to provide the memory needed for a transceiver’s interleaving and deinterleaving procedures. The first way is to provide a specified amount of dedicated interleaver memory and a specified amount of dedicated deinterleaver memory. The transmitter has exclusive access to the interleaver memory and can, at least in theory, use as much as all of the interleaver memory for interleaving. Similarly, the receiver has exclusive access to the deinterleaver memory and can, at least in theory, use as much as all of the deinterleaver memory for deinterleaving.

The second way to meet the transceiver’s memory requirements for interleaving and deinterleaving is to provide shared memory that the transceiver can partition between its interleaver and deinterleaver on a per-connection basis. Use of a shared memory for interleaving and deinterleaving, including in DSL, was well known before the priority date of the Family 3 patents.

Jacobsen Opening Report at ¶¶ 71-72 (emphasis added).



Thus, I stated, correctly, that the use of shared memory, as construed by the Court, for interleaving and deinterleaving was well known before the priority date of the Family 3 patents.

21. Furthermore, to the extent Dr. Cooklev characterizes the disclosures of the prior art references in this discussion, those characterizations are incorrect or misleading. For example, Dr. Cooklev contends that Berkmann does not disclose “shared memory” because “it is not being partitioned *between* the interleaving function and the deinterleaving function, and it is not being partitioned on a *per-connection* basis.” Cooklev Report at ¶ 60 (emphasis in original). Again, Dr. Cooklev’s focus on partitioning between an interleaving function and a deinterleaving function, and partitioning on a per-connection basis, is misplaced. The Court’s construction does not require memory to be partitioned between an interleaver and deinterleaver on a per-connection basis. In my Opening Report, I referred to certain prior art references as having the ability partition memory between an interleaver and a deinterleaver on a per connection basis for convenience. It is not my opinion that this ability is required to meet the claim limitations.

22. With respect to the disclosures of Kang, Dr. Cooklev merely provides his conclusion that “Kang does not disclose providing ‘shared memory that can be partitioned between its interleaver and deinterleaver on a per-connection basis,’ as Dr. Jacobsen asserts.” Cooklev Report at ¶ 62. He does not elaborate on how he reached that conclusion.

23. Dr. Cooklev argues, incorrectly, that Fadavi-Ardekani “teaches using dedicated memories for the interleaving function and deinterleaving function.” Cooklev Report at ¶ 61. I discussed the disclosures of Fadavi-Ardekani in my Opening Report and explained that Fadavi-Ardekani discloses “shared memory” as construed by the Court—namely, the Interleaver/De-Interleaver Memory (IDIM). *See, e.g.*, Jacobsen Opening Report at ¶¶ 357-62, 369-72.

24. Dr. Cooklev does not argue that Mazzoni does not disclose shared memory as construed by the Court; his argument is that, according to him, Mazzoni does not disclose “shared memory that can be partitioned between its interleaver and deinterleaver on a per-connection basis.” Cooklev Report at ¶ 63. As I explained above, Dr. Cooklev’s focus on this phrase is misplaced.

25. With respect to Voith, Dr. Cooklev argues that “Voith does not teach that the external memory is ‘shared memory.’” Cooklev Report at ¶ 64. On the contrary, and as I explained in my Opening Report, Voith discloses “common memory used by at least two functions, where a portion of the memory can be used by either one of the functions” as the Court’s construction requires. Specifically, I opined that Voith discloses “allocating memory between the interleaving function and the deinterleaving function” and that “a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time.” *See, e.g.*, Jacobsen Opening Report at ¶¶ 533-39, 557, 562-63.

26. Thus, I disagree with Dr. Cooklev’s assertions, in paragraphs 60-64, that the prior-art references do not disclose “shared memory” as construed by the Court.

## **V. THE FAMILY 3 PATENTS**

27. I incorporate by reference the Family 3 Patents section from my Rebuttal Report (*see* Section VIII, ¶¶ 45-50), which includes my response to Dr. Cooklev’s characterization of the Family 3 Patents.

## **VI. INVALIDITY UNDER 35 U.S.C. § 112**

28. Having considered Dr. Cooklev’s arguments to the contrary, it remains my opinion that claim 19 of the ’473 patent is indefinite and fails to meet the written description and/or enablement requirements of 35 U.S.C. § 112. In addition, it remains my opinion that the

Certificates of Correction for the '381 patent and the '882 patent were improperly obtained at least because they changed the scope of the issued claims.

**A. Claim 19 of the '473 Patent Is Indefinite Under 35 U.S.C. § 112, Paragraph 2.**

29. In attempting to rebut my argument that claim 19 of the '473 patent is indefinite under 35 U.S.C. § 112, paragraph 2, Dr. Cooklev asserts, incorrectly, that I ignored “context” provided by the Court in opining that the term “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message” is indefinite. Cooklev Report at ¶ 70. Dr. Cooklev quotes the Court’s statements:

The claim language does not require that the message specify amounts of memory. The disputed term’s language requires that the amount of memory depend on the message’s contents, but it does not require that the message’s contents themselves actually specify amounts of memory.

Cooklev Report at ¶ 70 (quoting Claim Construction Memorandum for Family 3 Patents (Dec. 18, 2017)). Dr. Cooklev has not explained how the Court’s statements, which address whether the message’s contents must specify amounts of memory, have any bearing on whether the language “a portion of the memory may be allocated” renders the claim indefinite, as I argued. In my opinion, these statements are not inconsistent with, nor are they germane to, my opinion that claim 19 is indefinite.

30. Dr. Cooklev then complains that I did not explain how the claims, specification, and file history support my argument that claim 19 is indefinite. Cooklev Report at ¶ 72. My argument, however, is that there is a lack of disclosure in the patent and its file history: it is not clear to a skilled artisan, when reading the claims, specification, and file history, whether the memory actually has to be allocated in more than one way in accordance with a message.

31. As I explained in my Opening Report, from the '473 patent's disclosure, one of ordinary skill in the art would have understood that, within the shared memory, a particular memory space may be allocated to the interleaver or the deinterleaver depending on the current demands of the system, and in turn, a message. Jacobsen Opening Report at ¶ 152. As I also explained, however, it is not clear from the intrinsic record whether this allocation actually has to happen, at some point, in order for a device to infringe. *Id.* For example, a system could use a shared memory in such a way that it is theoretically possible that a portion of the memory is allocated to a deinterleaver or an interleaver, depending on the message, but it might not actually ever happen in practice. *Id.* The support for my argument is the lack of disclosure of the '473 patent itself.

32. Dr. Cooklev suggests that I do not understand “the scope of an apparatus claim that defines structure in functional terms.” Cooklev Report at ¶ 73. But even if it is proper for an apparatus claim to “define[] structure in functional terms,” that is not, in my opinion, what a skilled artisan would understand claim 19 to do. As I explained in my Opening Report, claim 19 recites that “the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message,” and a skilled artisan would not understand whether this allocation actually has to occur for the claim to be infringed. *See* Jacobsen Opening Report at ¶ 152.

33. Tacitly recognizing that the language “may be allocated” is problematic, Dr. Cooklev argues that “the claim is infringed by transceivers that are capable of allocating at least a portion of the memory to the interleaving function or the deinterleaving function at any one particular time depending on the message,” (Cooklev Report at ¶ 73), but claim 19 does not recite that the transceiver is capable of allocating; it recites that “at least a portion of the

memory may be allocated to the interleaving function or the deinterleaving function,” thus suggesting that allocation in accordance with a message is optional. In contrast, the claim recites that the transceiver is “configured to . . . perform an interleaving function . . . and perform a deinterleaving function. . . ,” but not that it is “configured to allocate at least a portion of the memory to the interleaving function or the deinterleaving function at any one particular time depending on the message” or “capable of allocating at least a portion of the memory to the interleaving function or the deinterleaving function at any one particular time depending on the message.” Thus, I disagree with Dr. Cooklev’s assertion that “this claim language, as even the Court agreed, requires only that the function to which the portion of memory is allocated at one particular time depends on the message’s contents.” Cooklev Report at ¶ 74. As I understand the Court’s claim construction order, the Court did not agree with Dr. Cooklev’s statement, nor does the Court’s claim construction memorandum provide support for Dr. Cooklev’s argument.

34. Dr. Cooklev opines that “‘may’ is the most appropriate term given that the claim provides two possibilities on its face – that, depending on the message, (1) the portion of memory be allocated to the interleaver function at a particular time, or (2) the portion of memory be allocated to the deinterleaver function at a particular time.” Cooklev Report at ¶ 74. But that is not what “may be allocated” means. As a skilled artisan would have understood, the word “may” indicates that the memory need not be allocated at all. In other words, the plain language of claim 19 is that the allocation of the memory is optional. Dr. Cooklev frames his argument in terms of a transceiver that is “capable of” allocating, (Cooklev Report at ¶ 74), but, as I explained above, claim 19 does not recite that the transceiver is “capable of” allocating. It recites that “a portion of the memory may be allocated.”

35. Thus, having considered Dr. Cooklev's arguments to the contrary, it remains my opinion that claim 19 of the '473 patent is invalid as indefinite under 35 U.S.C. § 112, paragraph 2.

**B. The Asserted Claims Fail To Meet the Enablement and/or Written Description Requirements of 35 U.S.C. § 112, Paragraph 1.**

36. In paragraph 79, purporting to rebut my argument that “wherein the shared memory allocated to the [interleaver / deinterleaver] is used at the same time as the shared memory allocated to the [deinterleaver / interleaver]” (i.e., the last limitation of claim 1 of the '048 patent, claim 5 of the '381 patent, and claim 13 of the '882 patent) is not enabled and/or lacks written description, Dr. Cooklev concedes that “[t]he simultaneous use of memory by multiple functions was a well-known process at the time of the inventions.” Cooklev Report at ¶ 79. *See also id.* (“A POSITA at that time would know how two or more functions can simultaneously use the same memory by storing information for a first function at the same time that information for a second function is stored in the memory, or written to the memory, or read from the memory. This is inherent in any multi-threaded operation that uses the same memory.”).

37. Dr. Cooklev also contends that “simultaneous transmitting/encoding and decoding/receiving of the latency paths” amounts to “the shared memory allocated to the [deinterleaver / interleaver] is used at the same time as the shared memory allocated to the [interleaver / deinterleaver].” Cooklev Report at ¶ 81. Yet, as I explain below, when he addresses the disclosures of the prior-art references I applied in my Opening Report, Dr. Cooklev argues that these same types of disclosures are insufficient to meet the last limitation of claim 1 of the '048 patent, claim 5 of the '381 patent, and claim 13 of the '882 patent.

38. Finally, Dr. Cooklev argues that I did not explain why, in my opinion, the Family 3 patents fail to meet the written description requirement for the last limitation of claim 19 of the '473 patent, “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.” Cooklev Report at ¶ 82. On the contrary, I stated:

One of ordinary skill in the art would not have understood the patentee to have been in possession of an apparatus wherein at least a portion of the memory may be allocated to a first interleaving function or a second interleaving function at any one particular time depending on the message. The specification describes ways of allocating shared memory between an interleaving function and a deinterleaving function, but it does not describe to one of ordinary skill in the art how at least a particular portion of the memory can be allocated to one function, and then be allocated to the other function at any one particular time.

Jacobsen Opening Report at ¶ 156.

Thus, I did explain why the Family 3 patents fail to meet the written description requirement for “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.”

39. With respect to this limitation, Dr. Cooklev argues that “disclosure . . . is found generally because the specification discloses the use of ‘shared memory’ by an interleaver and a deinterleaver.” Cooklev Report at ¶ 82. He argues that “[a] POSITA would understand from the disclosure of shared memory that is allocated to an interleaver would not be used at the same time by a deinterleaver but, instead, could be used at alternative times depending on the allocation in effect at the time.” Cooklev Report at ¶ 82. Thus, Dr. Cooklev contends that the mere disclosure of shared memory by an interleaver and a deinterleaver discloses “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.” Yet, as I explain below, when

he addresses the disclosures of the prior-art references I applied in my Opening Report, Dr. Cooklev argues that the disclosure of “shared memory” is insufficient to meet the last limitation of claim 19 of the ’473 patent.

40. Having considered Dr. Cooklev’s arguments to the contrary, it remains my opinion that all of the asserted claims are invalid under 35 U.S.C. § 112, paragraph 1 for failing to meet the written description and/or enablement requirements.

**C. The Certificates of Correction In the ’381 and ’882 Patents Were Improperly Obtained Because They Changed the Scope and Meaning of the Issued Claims.**

41. Although Dr. Cooklev purports to disagree that the Certificates of Correction in the ’381 patent and the ’882 patent changed the scope of the issued claims, (Cooklev Report at ¶ 85), his argument focuses exclusively on whether the errors were “clerical or typographical.” Cooklev Report at ¶¶ 86-89. Dr. Cooklev does not actually dispute that the Certificates of Correction changed the scope of the issued claims. *See id.*

42. Dr. Cooklev states that I suggested “that the statement in the specification that ‘the invention can be applied to any transceiver having any number of latency paths’ somehow precludes the correction.” *Id.* at ¶ 87. On the contrary, I identified this statement as evidence that a skilled artisan would not have considered the issued claims to be in error. As I explained, the Family 3 patents state that “it should be appreciated that this invention can be applied to any transceiver having any number of latency paths,” which a person having ordinary skill would have understood to include transceivers that allocate “a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate” (as recited in the issued claims) and “a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded



data bytes received at a second data rate” (as recited in the issued claims). Jacobsen Opening Report at ¶ 159.

43. Dr. Cooklev does not rebut my argument that a skilled artisan “would have understood transmission and reception to be different, and that requiring transmission instead of reception, or vice versa, changes the required functionalities of the claimed transceivers.” Jacobsen Opening Report at ¶ 160; Cooklev Report at ¶¶ 85-89. Dr. Cooklev also does not dispute that “[a] skilled artisan would also have understood that a transceiver that did not infringe claim 5 of the ’381 patent or claim 13 of the ’882 patent as issued could infringe claim 5 of the ’381 patent and claim 13 of the ’882 patent as modified by the Certificates of Correction.” *Id.*

44. Thus, having considered Dr. Cooklev’s rebuttal, it remains my opinion that the Certificates of Correction were improperly obtained.

## **VII. ANALYSIS OF THE PRIOR ART**

45. Having considered Dr. Cooklev’s arguments to the contrary, it remains my opinion that each of the asserted claims of the Family 3 patents is rendered obvious by some or all of the following combinations:

- LB-031 in combination with the knowledge of a skilled artisan at the time of the alleged invention;
- LB-031 in combination with Mazzoni;
- Fadavi-Ardekani in combination with G.993.1;
- Fadavi-Ardekani in combination with G.992.2;
- Voith in combination with LB-031;
- Mazzoni in combination with G.993.1;
- Voith in combination with G.993.1; and/or
- Voith in combination with G.993.1 and Mazzoni.

**A. Recurring Issues In Dr. Cooklev's Rebuttal Report**

46. Before addressing Dr. Cooklev's specific arguments with respect to the references that render the asserted claims obvious, I highlight below three recurring issues in Dr. Cooklev's rebuttal report.

**1. DSL Standards in Existence On the Family 3 Patents' Priority Date Did Not Foreclose the Use of Shared Memory For Interleaving and Deinterleaving.**

47. Dr. Cooklev repeatedly asserts, without any support whatsoever, that DSL standards in existence as of the priority date of the Family 3 patents *required* the use of separate and dedicated interleaving memory and deinterleaving memory. *See, e.g.*, Cooklev Report at ¶ 42 ("DSL systems, such as, for example, ADSL2/2+ standards known at the time of the inventions, specify dedicated interleaving memory requirements in each transceiver separately for upstream and downstream transmission (i.e. in each direction separately). More specifically, an ADSL2/2+ ATU-C is required to have a specified amount of dedicated interleaving memory for downstream data transmission and separately and independently have a specified amount of dedicated interleaving memory for upstream data reception."); *id.* at ¶ 44 ("The ADSL2/2+ standards do not specify or enable memory sharing between the interleaver and the deinterleaver in a single transceiver.").

48. The ADSL2/2+ standards do not support Dr. Cooklev's assertions. As I explained above (*see supra*, § IV), none of the ADSL2/2+ standards specifies the use of dedicated memory for interleaving or deinterleaving or forbids the use of shared memory, construed by the Court to be "common memory used by at least two functions, where a portion of the memory can be used by either one of the functions." Furthermore, none of the standards on which Dr. Cooklev purports to rely even uses the word "memory." As I have explained, the standards do not specify or require any particular memory configuration for interleaving or

deinterleaving, much less the use of dedicated memory for interleaving and separate dedicated memory for deinterleaving. Whether a transceiver uses shared memory or dedicated memory for interleaving and deinterleaving is an implementation choice. Nothing in ADSL2/2+ would prohibit a transceiver from using shared memory, as construed by the Court, for interleaving and deinterleaving, and all of Dr. Cooklev's statements to the contrary are incorrect.

2. **Speculative and Unsupported Assertions That Prior-Art Transceivers Did Not Use Shared Memory.**

49. Dr. Cooklev also repeatedly asserts, without any support whatsoever, that all prior-art DSL transceivers used dedicated interleaving memory and dedicated deinterleaving memory. *See, e.g.*, Cooklev Report at ¶ 45 (“Prior to the inventions disclosed in the Family 3 patents, an amount of memory available to an interleaver was predetermined and an amount of memory available to a deinterleaver was predetermined. Those systems were incapable of sharing memory between an interleaving and deinterleaving function based on a message.”); *id.* at ¶ 102 (“LB-031 is perfectly consistent with the practice of its time, which was to use a dedicated, fixed-size interleaver memory and a separate, dedicated, fixed-size deinterleaver memory in a transceiver. . . . Thus, no portion of a memory can be used by either an interleaver or a deinterleaver.”); *id.* at ¶ 106 (same); *id.* at ¶ 276 (“The use of such dedicated memories is consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems. . . .”); *id.* at ¶ 290 (same); *id.* at ¶ 304 (same); *id.* at ¶ 312 (same); *id.* at ¶ 327 (same); *id.* at ¶ 332 (same); *id.* at ¶ 368 (same); *id.* at ¶ 379 (same); *id.* at ¶ 385 (same).

50. Dr. Cooklev has provided no support for these assertions. And, as I explained above, various prior art references in the DSL field disclose the use of shared memory, as recognized by the examiners during prosecution of the Family 3 patents. *See supra*, ¶¶ 15-26.

51. Furthermore, Dr. Cooklev does not purport to have determined how prior-art transceivers in general, or even just prior-art ADSL2/2+ transceivers specifically, implemented interleaving and deinterleaving. As I explained at Section VII.C of my Opening Report and in the later discussion of bases for invalidity, a number of systems prior to the time of the invention of the Family 3 patents used shared memory as construed by this Court. Additionally, and as I noted above, even though he worked for Aware from 2000 to 2002, Dr. Cooklev has not even stated whether Aware's transceivers operated as he contends, *i.e.*, using dedicated interleaving memory and dedicated deinterleaving memory. Furthermore, he has not represented that he has determined how other existing prior-art transceivers, whether for DSL or other applications, provided memory for interleaving and deinterleaving, much less that they did not use shared memory as construed by the Court. In my opinion, there is no basis whatsoever for Dr. Cooklev's conclusion that prior-art transceivers did not use shared memory for interleaving and deinterleaving.

3. **Incorrect Assumption That A Skilled Artisan Would Not Be Able to Modify Aspects of a Reference When Making a Combination.**

52. In attempting to rebut my arguments that a skilled artisan would have been motivated to combine the teachings of a first reference with the teachings of a second reference in the manner claimed, Dr. Cooklev repeatedly assumes that the skilled artisan would merely have attempted to combine the teachings of the references without any modification at all, and, if the resulting combination would not work, would have abandoned all attempts to combine those references. *See, e.g.*, Cooklev Report at ¶ 210 ("A POSITA would not look to add a message (from LB-031 or otherwise) to the system disclosed in Mazzoni, and in fact doing so would provide no useful benefit. This is because the system disclosed in Mazzoni relies on the use of a pre-populated table of I, M, I' and M' parameter values. . . . There is no use for a

message. . . .”); *id.* at ¶ 211 (“An additional reason why LB-031’s exchange of maximum supported memory sizes would not be recognized as beneficial to Mazzoni is that it is incompatible.”); *id.* at ¶ 298 (“a POSITA would recognize that this implementation would be inoperable with G.993.1.”); *id.* at ¶ 206 (“One of skill in the art at the time would have understood that many of these references would be completely incompatible with one another and/or, if combined, would provide no useful benefit.”); *id.* at ¶ 296 (same); *id.* at ¶ 317 (same); *id.* at ¶ 344 (same); *id.* at ¶ 375 (same); *id.* at ¶ 382 (same); *id.* at ¶ 347 (“A POTISA would not look to add a message (from G.993.1 or otherwise) to the system disclosed in Mazzoni, and in fact doing so would provide no useful benefit. This is because the system disclosed in Mazzoni relies on the use of a pre-populated table of I, M, I’ and M’ parameter values. . . . There is no use for a message. . . .”).

53. I disagree. In my Opening Report, I set forth my understanding of the conditions and factors that would have led a skilled artisan to combine the teachings of multiple references in the manner claimed. Jacobsen Opening Report at ¶¶ 21-27. With that understanding, I have more faith than Dr. Cooklev does in the abilities of the skilled artisan as of the Family 3 patents’ priority date to have recognized how the disclosures of the different references could be combined. For example, and as I explain in more detail below with respect to specific combinations of references, the skilled artisan would have recognized the shortcomings of the individual references and would have considered the teachings of other references that could be incorporated, with or without modification, to address or mitigate those shortcomings. Thus, I do not agree with Dr. Cooklev’s conclusions that a skilled artisan would not have been motivated to combine references simply because bolting them together wholesale and without any modification would not make sense.

**B. LB-031 Renders the Asserted Claims Obvious.**

54. As explained below, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that LB-031 renders obvious claim 1 of the '048 patent, claim 5 of the '381 patent, claim 13 of the '882 patent, and claim 19 of the '473 patent.

55. Dr. Cooklev concedes that LB-031 was publicly available as of the priority date of the Family 3 patents.

**1. Claim 1 of the '048 Patent**

56. Having considered Dr. Cooklev's arguments to the contrary, it remains my opinion that LB-031 in view of the knowledge of one of ordinary skill in the art at the time of the alleged invention renders claim 1 of the '048 patent obvious.

a. 1[a]. "A system that allocates shared memory"

57. Dr. Cooklev argues that LB-031 does not disclose "[a] system that allocates shared memory." Cooklev Report at ¶¶ 99-110. He takes issue with my statement that a person having ordinary skill in the art would have understood an example in LB-031 to teach allocating memory for interleaving and deinterleaving. Cooklev Report at ¶ 100. Specifically, Dr. Cooklev contends that the example in LB-031—that "[i]f the minimum interleaver delay requirement were 5.23 ms, then, from equation (5) and equation (1), this transceiver must support a delay of at least 29092 octets which corresponds to having an interleaver memory of *at least* 14546 octets according to equation (2)" (LB0031 at 4 (emphasis in original))—does not teach allocating a shared memory between an interleaver and a deinterleaver within a single transceiver. Cooklev Report at ¶¶ 100-01. He notes that LB-031 "is describing the memory requirements for an interleaver in one transceiver and the corresponding memory requirements for a deinterleaver in a second transceiver at the other end of the communication channel." Cooklev Report at ¶ 101. Dr. Cooklev accuses me of "omitting," "ignoring," or "attempting to

confuse” the “fundamental detail” that the equations of LB-031 “separately characterize the delay and memory requirements for a single latency path/direction.” Cooklev Report at ¶¶ 102, 103. I disagree with Dr. Cooklev’s characterization of my opinion.

58. First, I explained in my discussion of the background of the technology that the “process of interleaving in the transmitter and deinterleaving in the receiver” results in an “end-to-end interleaver delay (with the understanding that the delay contributed by the deinterleaving process is included, too).” Jacobsen Opening Report at ¶ 66. I also explained in my discussion of LB-031 that LB-031 considers end-to-end interleaving delay. *See, e.g.*, Jacobsen Opening Report at ¶¶ 166-77. Furthermore, the equation I provided at paragraph 67, in the technology background section, as representing the minimum amount of memory required for an interleaver/deinterleaver pair is the same as Equation (1) of LB-031. *Compare* Jacobsen Opening Report at ¶ 67 *with id.* at ¶ 166. Nothing about my discussion of LB-031 misleading, nor does it “omit,” “ignore,” or “attempt to confuse” that the end-to-end delay involves the interleaver in one transceiver and the deinterleaver in a different transceiver.

59. Second, the implication of Dr. Cooklev’s argument is that, having an understanding of the disclosures of LB-031 and the memory requirements stemming from a specified end-to-end delay, a person having ordinary skill in the art would not have understood that the teachings of LB-031 would apply to both the downstream and upstream transmission directions. In other words, Dr. Cooklev’s argument requires the skilled artisan not to have recognized that the VDSL2 transceiver contemplated by LB-031 would need to perform both interleaving in the transmit direction and deinterleaving in the receive direction, even though LB-031 states that, after exchanging capabilities, “[t]he VTU-O and VTU-R would then select the smaller of the transmitter and receiver capabilities, in each direction, as the end-to-end

capabilities.” LB-031 at p. 3 (emphasis added). According to Dr. Cooklev’s argument, the skilled artisan would not have recognized that the example provided in LB-031 would apply to both transmission directions, and therefore would, in fact, specify a minimum amount of interleaver memory (for transmission) and a minimum amount of deinterleaver memory (for reception) that the transceiver would need to perform both interleaving and deinterleaving. I disagree that the skilled artisan would not have made this connection.

60. Dr. Cooklev opined in the “Expert Report of Dr. Todor Cooklev, Ph.D., Regarding Infringement of the Family 3 Patents” (“Cooklev Opening Infringement Report”) that “a POSITA at the time of the invention had (i) a Bachelor’s degree in Electrical Engineering or a related field, and (ii) two to three years’ of experience working in DSL or other broadband communications (or a Master’s Degree in Electrical Engineering or a related field, particularly with an emphasis in the area of communications).” Cooklev Opening Infringement Report at ¶ 27. As I explained in my rebuttal to that report and also in my Opening Report (*see, e.g.*, Jacobsen Opening Report at ¶ 45), it is my opinion that the level of skill was higher than Dr. Cooklev has opined; nevertheless, even a person having the level of skill suggested by Dr. Cooklev would have understood that a DSL transceiver would include a transmitter that would perform interleaving and a receiver that would perform deinterleaving. Thus, even Dr. Cooklev’s skilled artisan would have recognized that the example I cited from LB-031 would apply to both transmission directions.

61. Dr. Cooklev also contends that “Dr. Jacobsen has not identified any disclosure in LB-031 that requires that a shared memory is used or that any portion of memory within a single transceiver can be used by the interleaver or the deinterleaver.” Cooklev Report at ¶ 106. But I did not opine that LB-031 requires the use of a shared memory; I opined that one of



ordinary skill in the art would have understood from the disclosures of LB-031 that the allocated memory can be a shared memory, which is something that was known in the art as of the Family 3 patents' priority date. Jacobsen Opening Report at ¶ 181; *see also supra*, § VII.A.2; *supra*, ¶¶ 15-26.

62. Dr. Cooklev asserts—without any citation or support—that “LB-031 is perfectly consistent with the practice of its time, which was to use a dedicated, fixed-size interleaver memory and a separate, dedicated, fixed-size deinterleaver memory in a transceiver,” and that “no portion of a memory can be used by either an interleaver or a deinterleaver.” Cooklev Report at ¶ 106. As I explained *supra*, (*see, e.g.*, ¶ 17), Dr. Cooklev has not identified any basis for this assertion, which, in my opinion, amounts to speculation. *See also supra*, § VII.A.2.

63. Dr. Cooklev then asserts that because LB-031 teaches that the size of the interleaver memory will be “a major source of complexity in VDSL2,” (LB-031 at p. 1), a skilled artisan would be discouraged “from attempting add further complexity to interleaver memory in VDSL2, such as by proposing a memory sharing scheme.” Cooklev Report at ¶ 107. Dr. Cooklev asserts that “a shared memory implementation would increase and not decrease the complexity of the implementation proposed by the LB-031 reference.” Cooklev Report at ¶ 108. As an initial matter, Dr. Cooklev's argument is inconsistent with and contrary to his contention in his opening report on infringement that the use of shared memory allows “the combined amount of interleaver memory and deinterleaver memory required for a transceiver [to be] approximately cut by half.” Cooklev Opening Infringement Report at ¶ 86. Assuming Dr. Cooklev is correct that memory sharing reduces the amount of memory required in a transceiver by approximately half, he has not explained why that reduction would not have been

recognized or understood by a person having ordinary skill in the art as of the Family 3 patents' priority date.

64. Additionally, Dr. Cooklev has not explained why he contends that a shared memory implementation would actually increase the complexity of the implementation proposed by LB-031, or why a skilled artisan would understand it to do so. *See* Cooklev Rebuttal Report, ¶¶ 107-08. The references I discussed in my Opening Report say just the opposite. For example, Mazzoni teaches that a shared memory “has a first memory space assigned to the interleaving means and a second memory space assigned to the deinterleaving means,” which enables a considerable reduction in “the size of the memory means required for the interleaving and deinterleaving means implemented within a modem.” Mazzoni at col. 2:10-21. Voith teaches that “in order to minimize the number of integrated circuit pins required to access external memory, the interleave and de-interleave buffers are also preferably implemented in the same physical memory and digital interface unit 3 preferably multiplexes between interleaving and de-interleaving operations.” Voith at col. 4:35-40. Fadavi-Ardekani, which teaches the use of a shared memory for interleaving and deinterleaving, states that the disclosed “buffering and scheduling scheme for synchronizing the digital signal processing tasks for multiple asynchronous ADSL lines” allows “the various components of the ADSL transceiver [] to operate seamlessly (i.e., in a semi-synchronous fashion) and the design sizes of various transceiver components and the data flow complexity of the transceiver [to be] reduced.” Fadavi-Ardekani at col. 4:11-18. In my opinion, a skilled artisan would have understood all of Mazzoni, Voith, and Fadavi-Ardekani to teach that using shared memory decreases complexity by decreasing at least the size of the memory and the number of integrated circuit pins required to access the memory. Therefore, I disagree with Dr. Cooklev's assertions

that any of the references would “increase complexity of the implementation of the LB-031 disclosure.” Cooklev Report at ¶ 109.

65. Dr. Cooklev asserts that there would be no motivation to combine any of the references cited in paragraph 182 of my Opening Report with LB-031. Cooklev Report at ¶¶ 109, 110. Notwithstanding that this portion of Dr. Cooklev’s report purports to address my argument that LB-031 combined with the knowledge of a skilled artisan as of the alleged invention date renders the asserted Family 3 claims obvious, Dr. Cooklev is incorrect. As I explained in my Opening Report, a skilled artisan would have been motivated to combine the teachings of at least LB-031 and Mazzoni (Jacobsen Opening Report at ¶¶ 345-50) and LB-031 and Voith (*id.* at ¶¶ 566-569).

66. Therefore, it remains my opinion that a person having ordinary skill in the art as of the Family 3 patents’ priority date would have understood LB-031 to disclose the preamble, element 1[a], of claim 1 of the ’048 patent, to the extent that it is limiting.

b. 1[b]. “a transceiver that is capable of”

67. Dr. Cooklev concedes that LB-031 discloses a transceiver. *See, e.g.*, Cooklev Report at ¶¶ 90-192.

c. 1[c]. “transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver”

68. Dr. Cooklev concedes that the transceiver of LB-031 is capable of “transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver” under TQ Delta’s interpretation of the limitation.<sup>3</sup> *See, e.g.*, Cooklev Report at ¶¶ 90-192.

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<sup>3</sup> As I explained in my Opening Report (*see, e.g.*, ¶ 188), I do not agree with TQ Delta’s interpretation that transmission or reception of the O-PMS message of VDSL2 meets this

- d. 1[d]. “determining an amount of memory required by the interleaver to interleave a plurality of Reed Solomon (RS) coded data bytes within the shared memory”

69. Dr. Cooklev argues that the transceiver of LB-031 is not capable of “determining an amount of memory required by the interleaver to interleave a plurality of Reed Solomon (RS) coded data bytes within the shared memory.” Cooklev Report at ¶¶ 111-14. Dr. Cooklev’s argument is based solely on his opinion that LB-031 does not disclose “shared memory.” *Id.* at ¶ 113.

70. I disagree. As I explained in my Opening Report (*see* Jacobsen Opening Report at ¶¶ 179-83) and *supra* (*see* § VII.B.1.a) a skilled artisan would have understood LB-031 to disclose “[a] system that allocates shared memory.” In turn, a skilled artisan would also have understood LB-031 to disclose element 1[d].

71. Therefore, it remains my opinion that LB-031 discloses element 1[d].

- e. 1[e]. “allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate”

72. Dr. Cooklev opines that LB-031 does not disclose, teach, or suggest “allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate.” Cooklev Report at ¶ 115. Again, Dr. Cooklev’s argument is based on his conclusion that “LB-031 lacks disclosure of a shared memory as construed by the Court.” Cooklev Report at ¶ 116. I disagree. As I explained in my Opening Report (*see* Jacobsen Opening Report at ¶¶ 179-83) and *supra* (*see* § VII.B.1.a) a skilled artisan would have understood LB-031 to disclose “[a] system that allocates shared memory.”

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limitation, but to the extent the Court or fact-finder agrees with this interpretation, LB-031 also meets this limitation.

73. Dr. Cooklev also complains that the statement in LB-031 that “[t]he VTU-O and VTU-R would then select the smaller of the transmitter and receiver capabilities, in each direction, as the end-to-end capabilities” would only apply to “e.g., interleaver capabilities of the VTU-O and deinterleaver capabilities of the VTU-R for the downstream direction.” Cooklev Report at ¶ 117. To the extent Dr. Cooklev is suggesting that the disclosures of LB-031 apply only to the downstream direction, I disagree. LB-031 is clear that the VTU-O and VTU-R select transmitter and receiver capabilities in both transmission directions. *See, e.g.*, LB-031 at p. 3. Consequently, and as I explained above, a skilled artisan would have understood LB-031 to address both the VTU-O’s interleaving and deinterleaving requirements, and the VTU-R’s interleaving and deinterleaving requirements, in whatever way they are implemented.

74. Therefore, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that LB-031 discloses element 1[e].

- f. 1[f]. “wherein the allocated memory for the interleaver does not exceed the maximum number of bytes in the message”

75. Dr. Cooklev argues that LB-031 does not disclose “wherein the allocated memory for the interleaver does not exceed the maximum number of bytes in the message.” Cooklev Report at ¶ 119. The entirety of Dr. Cooklev’s argument is that “LB-031 does not disclose, teach, or suggest transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver.” Cooklev Report at ¶ 120. Dr. Cooklev is incorrect. As noted above (*see supra* ¶ 68), Dr. Cooklev conceded that LB-031 discloses element 1[c]: “transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver.” Therefore, Dr. Cooklev’s “argument” is merely a conclusory

statement that does not rebut my opinion, set forth in my Opening Report (*see* ¶¶ 196-200), that LB-031 discloses element 1[f]. To the extent that Dr. Cooklev changes or corrects this opinion at a later date, I reserve the right to respond.

76. Therefore, having considered Dr. Cooklev’s statement to the contrary, it remains my opinion that LB-031 discloses “wherein the allocated memory for the interleaver does not exceed the maximum number of bytes specified in the message.”

g. 1[g]. “allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate”

77. Dr. Cooklev asserts that LB-031 does not disclose, teach, or suggest “allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate.” Cooklev Report at ¶ 121. Dr. Cooklev’s argument relies once again on his assertion that “LB-031 lacks disclosure of shared memory as construed by the Court.” *Id.* at ¶ 123. Specifically, Dr. Cooklev argues that “[t]here is no disclosure or contemplation of sharing a memory within a single transceiver for an interleaver operating in a first direction and a deinterleaver operating in a second direction.” *Id.* at ¶ 124. I disagree because, as I explained above (*see, e.g., supra*, ¶¶ 58-66), a skilled artisan would have understood LB-031 to address both the VTU-O’s interleaving and deinterleaving requirements, and the VTU-R’s interleaving and deinterleaving requirements, however they are implemented, including with shared memory.

78. Therefore, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that LB-031 discloses element 1[g].

- h. 1[h]. “interleaving the first plurality of RS coded data bytes within the shared interleaver memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver”

79. Dr. Cooklev argues that LB-031 does not disclose, teach, or suggest “interleaving the first plurality of RS coded data bytes within the shared interleaver memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver.” Cooklev Report at ¶ 126. Dr. Cooklev states again that “LB-031 is consistent with the practice at that time of using a dedicated interleaver memory and a separate deinterleaver memory.” *Id.* at ¶ 128. I disagree because, as I explained above (*see, e.g., supra*, § VII.A.2), Dr. Cooklev’s opinion amounts to speculation as to how transceivers implemented interleaver and deinterleaver memory. Dr. Cooklev has not provided any support for his assertion that “the practice at that time” was to use “dedicated interleaver memory and a separate deinterleaver memory.”

80. As I explained in my Opening Report, a skilled artisan would have understood LB-031 to disclose a transceiver with a convolutional interleaver, which would operate to interleave RS coded data bytes at the transmitter and a convolutional deinterleaver, which would operate to deinterleave RS coded data bytes, and that the interleaver and deinterleaver could use shared memory. Jacobsen Opening Report at ¶¶ 179-83, 205; *see also supra*, ¶¶ 58-66. Because LB-031 discloses a VDSL2 VTU-O and VTU-R in communication with each other, one of ordinary skill in the art would have understood that the VTU-O (or VTU-R) would interleave the first plurality of RS coded data bytes within the shared interleaver memory allocated to the interleaver, and the deinterleaver would deinterleave the second plurality of RS code data bytes within the shared memory allocated to the deinterleaver. Jacobsen Opening Report at ¶ 205.

81. Thus, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that LB-031 discloses element 1[h].

- i. 1[i]. "wherein the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver"

82. Dr. Cooklev's argument that LB-031 does not disclose element 1[i] is based on his assertion that "LB-031 does not disclose allocating shared memory in a single transceiver." Cooklev Report at ¶¶ 131-34. As I explained above, a skilled artisan would have understood the disclosures of LB-031 to extend to implementations in which the interleaver and deinterleaver use shared memory. *See supra*, ¶¶ 58-66. And because, as a person having ordinary skill in the art as of the priority date of the Family 3 patents would have understood, VDSL transceivers transmit and receive data at the same time, the deinterleaver must be able to read from, write to, or hold information for deinterleaving in the portion of memory allocated to the deinterleaver at the same time the interleaver is able to read from, write to, or hold information for interleaving in the portion of memory allocated to the interleaver. Jacobsen Opening Report at ¶ 207.

83. Consequently, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that LB-031 discloses element 1[i]. In addition, it remains my opinion that LB-031 discloses all of the limitations of claim 1 of the '048 patent.

## 2. Claim 5 of the '381 Patent

84. It remains my opinion that LB-031 in view the knowledge of one of ordinary skill in the art renders claim 5 of the '381 patent obvious.

- a. 5[a]. "A non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver"

85. As I opined in my Opening Report, it is my opinion that LB-031 discloses the preamble, to the extent it is limiting. *See* Jacobsen Opening Report at ¶¶ 209-10. As I



explained, one of ordinary skill in the art would have understood that methods such as the one recited in claim 5 of the '381 patent could be accomplished by a processor executing instructions stored on computer-readable information storage media. *Id.* at ¶ 110. Moreover, as I explained, a skilled artisan would have understood that the disclosures of LB-031 would extend to shared memory, the use of which was well known as of the Family 3 patents' priority date. *See supra*, ¶¶ 58-66.

86. Dr. Cooklev appears to assert that because "one or more of the claimed functions could be implemented in hardware, and therefore would not necessarily have to be carried out through an execution of instructions stored on a non-transitory computer-readable media," LB-031 does not disclose the preamble of claim 5. Cooklev Report at ¶ 141. I disagree. First, according to Dr. Cooklev, "a POSITA at the time of the invention had (i) a Bachelor's degree in Electrical Engineering or a related field, and (ii) two to three years' of experience working in DSL or other broadband communications (or a Master's Degree in Electrical Engineering or a related field, particularly with an emphasis in the area of communications)." Cooklev Opening Infringement Report at ¶ 27. A person having the level of skill suggested by Dr. Cooklev would have understood that transceivers include hardware and software, and therefore the universe of ways to implement a transceiver as taught by LB-031 extends to hardware, software, or some combination of the two. That LB-031 does not explicitly refer to a particular approach does not mean that a skilled artisan would not have understood that approach to be disclosed.

87. Second, because LB-031 discloses equations that depend on settings and capabilities determined during the initialization procedure, a skilled artisan would have understood the most likely way the transceiver disclosed in LB-031 would implement these

equations would be in software, i.e., via instructions that would be executed by a processor.

*See, e.g.*, LB-031 at p. 2-5.

88. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that LB-031 discloses the preamble of claim 5.

- b. 5[b]. “transmitting or receiving, by the transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver”

89. Dr. Cooklev concedes that LB-031 discloses “transmitting or receiving, by the transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver” under TQ Delta’s interpretation of the limitation. *See, e.g.*, Cooklev Report at ¶¶ 90-192.

- c. 5[c]. “determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory”

90. Dr. Cooklev disputes that LB-031 discloses “determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory.” Dr. Cooklev’s rebuttal refers to his arguments with respect to element 1[d]. I explained above (*see supra*, § VII.B.1.d) why I disagree with Dr. Cooklev.

91. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that LB-031 discloses “determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory.”

- d. 5[d] “allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate”

92. Dr. Cooklev disputes that LB-031 discloses “allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate.” Dr. Cooklev’s rebuttal refers to his arguments with respect to elements 1[e] and 1[g]. I explained above (*see supra*, § VII.B.1.e, § VII.B.1.g) why I disagree with Dr. Cooklev.

93. Consequently, it remains my opinion that LB-031 discloses “allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate.”

- e. 5[e]. “wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message”

94. Dr. Cooklev’s rebuttal for element 5[e] refers to his arguments with respect to element 1[f]. I explained above (*see supra*, § VII.B.1.f) why I disagree with Dr. Cooklev.

95. Consequently, it remains my opinion that LB-031 discloses “wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message.”

- f. 5[f]. “allocating, in the transceiver, a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate”

96. Dr. Cooklev’s rebuttal refers to his arguments with respect to elements 1[e] and 1[g]. I explained above (*see supra*, § VII.B.1.e, § VII.B.1.g) why I disagree with Dr. Cooklev.

97. Consequently, it remains my opinion that LB-031 discloses “allocating, in the transceiver, a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate.”

- g. 5[g]. “deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver”

98. Dr. Cooklev’s rebuttal for element 5[g] refers to his arguments with respect to element 1[h]. I explained above (*see supra*, § VII.B.1.h) why I disagree with Dr. Cooklev.

99. Consequently, it remains my opinion that LB-031 discloses “deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver.”

- h. 5[h]. “wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver”

100. Dr. Cooklev’s rebuttal for element 5[h] refers to his arguments with respect to element 1[i]. I explained above (*see supra*, § VII.B.1.i) why I disagree with Dr. Cooklev.

101. Consequently, it remains my opinion that LB-031 discloses “wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver.” In addition, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that LB-031 discloses all of the limitations of claim 5 of the ’381 patent.

### **3. Claim 13 of the ’882 Patent**

102. It remains my opinion that LB-031 in view the knowledge of one of ordinary skill in the art renders claim 13 of the ’882 patent obvious.

- a. 13[a]. “A system that allocates shared memory”

103. Dr. Cooklev’s rebuttal for element 13[a] refers to his argument with respect to element 1[a]. I explained above (*see supra*, § VII.B.1.a) why I disagree with Dr. Cooklev.

104. Consequently, it remains my opinion that LB-031 discloses “[a] system that allocates shared memory.”

b. 13[b]. “a transceiver that performs”

105. Dr. Cooklev concedes that LB-031 discloses a transceiver. *See, e.g.*, Cooklev Report at ¶¶ 90-192.

c. 13[c]. “transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver”

106. Dr. Cooklev concedes that the transceiver of LB-031 is capable of “transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver” under TQ Delta’s interpretation of the limitation. *See, e.g.*, Cooklev Report at ¶¶ 90-192.

d. 13[d] through 13[i].

107. Dr. Cooklev’s rebuttal for elements 13[d] through 13[j] refers to his argument with respect to elements 5[c] through 5[h]. I explained above (*see supra*, §§ VII.B.2.c-VII.B.2.h) why I disagree with Dr. Cooklev.

108. Consequently, it remains my opinion that LB-031 discloses elements 13[d] through 13[i] of claim 13 of the ’882 patent. In addition, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that LB-031 discloses all of the limitations of claim 13 of the ’882 patent.

**4. Claim 19 of the ’473 Patent**

109. Having considered Dr. Cooklev’s arguments to the contrary, it remains my opinion that LB-031 discloses each limitation of claim 19 of the ’473 patent.

a. 19[a]. “An apparatus comprising”

110. Dr. Cooklev concedes that LB-031 discloses an apparatus. *See, e.g.*, Cooklev Report at ¶¶ 164-92.

b. 19[b]. “a multicarrier communications transceiver that is configured to perform an interleaving function associated with a

first latency path and perform a deinterleaving function associated with a second latency path”

111. Dr. Cooklev concedes that LB-031 discloses “a multicarrier communications transceiver that is configured to perform an interleaving function associated with a first latency path and perform a deinterleaving function associated with a second latency path.” *See, e.g.*, Cooklev Report at ¶¶ 164-92.

c. 19[c]. “the multicarrier communications transceiver being associated with a memory”

112. Dr. Cooklev concedes that LB-031 discloses “the multicarrier communications transceiver being associated with a memory.” *See, e.g.*, Cooklev Report at ¶¶ 164-92.

d. 19[d]. “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver”

113. Dr. Cooklev contends that “LB-031 does not disclose, teach, or suggest a multicarrier transceiver being associated with a memory wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during initialization of the transceiver.” Cooklev Report at ¶ 171. Specifically, he argues that “no portion of any memory contemplated by LB-031 is used as interleaver memory at one point in time and deinterleaver memory at another point in time and, thus, LB-031 does not allocate memory *between* an interleaving function and a deinterleaving function.” *Id.* at ¶ 172.

114. Without any support whatsoever, Dr. Cooklev states that “one of ordinary skill in the art would understand LB-031 in the context of a system in which the CO transceiver (VTU-O) has a dedicated amount of memory available to be used for downstream interleaving and a separate, dedicated amount of memory available to be used for upstream deinterleaving and the CPE transceiver (VTU-R) has a dedicated amount of memory available to be used for

downstream deinterleaving and a separate, dedicated amount of memory available to be used for upstream interleaving.” *Id.* I disagree. As I explained (*see supra*, ¶ 62), Dr. Cooklev has not explained why, in his opinion, a skilled artisan would not have understood the disclosures of LB-031 to extend not only to implementations using dedicated interleaving and deinterleaving memories, but also implementations using shared memory as disclosed in various prior-art references. *See, e.g., supra*, § VII.A.2.

115. Dr. Cooklev argues that “[e]ven assuming the exchange of information described in LB-031 occurs during initialization and occurs through an exchange of messages, LB-031 would not disclose to a person of ordinary skill in the art a message that is used to perform the claimed allocation.” Cooklev Report at ¶ 174. Based on the disclosures in LB-031 that “[i]f a VDSL2 implementation supports a larger interleaver memory than is required, it should be free to specify the larger value,” in which case “[t]he VTU-O and VTU-R would then select the smaller of the transmitter and receiver capabilities, in each direction, as the end-to-end capabilities,” Dr. Cooklev sets forth a four-step messaging and selection procedure that, according to him, a skilled artisan would have understood to occur. Cooklev Report at ¶ 174. He then concludes that that “no portion of memory is allocated between the interleaving function and the deinterleaving function in accordance with a message. Cooklev Report at ¶ 175.

116. I disagree with both Dr. Cooklev’s hypothetical messaging and selection procedure and his conclusion. Dr. Cooklev’s hypothetical messaging sequence, which appears nowhere in LB-031, presumes that the downstream and upstream interleaving negotiations are independent of each other, which is a result of his assumption that the VTU-O and VTU-R use dedicated interleaving and deinterleaving memories. In other words, Dr. Cooklev’s messaging

and selection procedure presume his conclusion. In my opinion, a skilled artisan would have understood that the guidance of LB-031—that “[i]f a VDSL2 implementation supports a larger interleaver memory than is required, it should be free to specify the larger value,” in which case “[t]he VTU-O and VTU-R would then select the smaller of the transmitter and receiver capabilities, in each direction, as the end-to-end capabilities”—would apply regardless of whether a VTU-O or VTU-R implements interleaving and deinterleaving using a shared memory or dedicated memory. And, as I have explained (*see, e.g., supra* ¶¶ 15-26, § VII.A.2), the use of shared memory for interleaving and deinterleaving was well known in the art and would have been known to a person having ordinary skill in the art considering the disclosures of LB-031.

117. Dr. Cooklev opines that “LB-031 at most discloses that, for the downstream direction, a VTU-R with larger dedicated deinterleaver memory than is required can determine whether the VTU-O also supports a larger amount.” Cooklev Report at ¶ 176. He then argues that “if the VTU-O does not support a larger amount than is required, . . . the extra deinterleaver memory of the VTU-R is simply not used. *Id.* Again, I disagree, because Dr. Cooklev’s conclusion presumes, again without justification, that the VTU-R implements interleaving and deinterleaving using dedicated memories. As I explained in my Rebuttal Report (*see, e.g., Jacobsen Rebuttal Report at § VII.C, § VII.E, § IX*), none of the VDSL standards specifies that a VTU-O or VTU-R must implement interleaving and deinterleaving using either dedicated or shared memory.

118. Paragraphs 177-86 of Dr. Cooklev’s report are substantially identical to paragraphs 48-57, except Dr. Cooklev refers specifically to LB-031 in paragraphs 177-86. I



explained above (*see, e.g.*, ¶¶ 17-18) why I disagree with Dr. Cooklev's conclusions with respect to his hypothetical example.

119. In paragraph 180, Dr. Cooklev states, without support, that “[b]ecause the smaller of the capabilities of the transmitter or receiver are selected in each direction in accordance with the express teaching of LB-031, unused memory for one function in a transceiver cannot be used for another function, e.g., unused dedicated deinterleaver memory in the VTU-R cannot be used for the interleaving function.” Again, I disagree. LB-031 says nothing to indicate that the VTU-O and VTU-R described use dedicated interleaver memory and dedicated deinterleaver memory. And, as I have stated, in my opinion a skilled artisan would have understood the disclosures of LB-031 to apply regardless of whether an implementation used dedicated memories or shared memory for interleaving and deinterleaving.

120. Consequently, I disagree with Dr. Cooklev's statement that LB-031 “allows a transceiver to determine how much of its pre-allocated downstream memory (i.e., interleaver memory in the VTU-O and deinterleaver memory in the VTU-R) and how much of its pre-allocated upstream memory (i.e., deinterleaver memory in the VTU-O and interleaver memory in the VTU-R) can be used.” Cooklev Report, ¶ 187. Dr. Cooklev has presumed, without justification, that a skilled artisan would not have understood the disclosures of LB-031 to apply regardless of whether an implementation of a VTU uses dedicated memories or shared memory for interleaving and deinterleaving.

121. Therefore, having considered Dr. Cooklev's arguments to the contrary, it remains my opinion that LB-031 discloses “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.”

- e. 19[e]. “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message”

122. Dr. Cooklev disputes that LB-031 discloses that “at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.” Dr. Cooklev’s conclusion is based solely on his incorrect assertion that “LB-031 does not disclose any sharing of memory within a transceiver.” Cooklev Report at ¶ 189. *See also id.* at ¶ 190. I explained above (*see, e.g.*, § VII.B.1.a) why a skilled artisan would have understood the disclosures of LB-031 to apply to all VTU implementations, regardless of whether they use dedicated or shared memory for interleaving and deinterleaving.

123. Furthermore, as I explained at paragraph 342 of my Opening Report (with respect to LB-031 in combination with Mazzoni), LB-031 teaches that at least a portion of the memory allocated to the interleaving function or the deinterleaving function at any one particular time is dependent on the message.<sup>4</sup> As I also explained in my Opening Report, (*see* Jacobsen Opening Report at § IX.A.2), LB-031 teaches that the VTU-O and VTU-R exchange the interleaver delay during initialization, and that the minimum amount of memory required to meet that delay is half of the interleaving delay. LB-031 at pp. 3, 4. Thus, the amount of memory required to meet the interleaving delay changes with the interleaving delay, which is exchanged via an initialization message, which means that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.

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<sup>4</sup> This paragraph was inadvertently omitted from my discussion of LB-031, but it appears where I discussed LB-031 in combination with Mazzoni.

124. Therefore, having considered Dr. Cooklev's arguments to the contrary, it remains my opinion that LB-031 discloses all of the limitations of claim 19 of the '473 patent.

**C. LB-031 in Combination With Mazzoni Renders the Asserted Claims Obvious**

125. As explained below, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that LB-031 in combination with Mazzoni renders obvious claim 1 of the '048 patent, claim 5 of the '381 patent, claim 13 of the '882 patent, and claim 19 of the '473 patent.

**1. Motivation to Combine LB-031 and Mazzoni**

126. Dr. Cooklev disputes that a person having ordinary skill in the art would have been motivated to combine the teachings of Mazzoni and LB-031 in the manner claimed by the asserted claims of the Family 3 patents. Cooklev Report at ¶ 204. I disagree.

127. Dr. Cooklev argues that my statement that "both Mazzoni and LB-031 are concerned with limiting the size of memory used for interleaving and deinterleaving" is inaccurate. Cooklev Report at ¶ 207-08. Dr. Cooklev contends that "LB-031 actually wastes memory by leaving portions of memory unused where one transceiver supports more memory for a given latency path than is supported by the other transceiver with which it is communicating." Cooklev Report at ¶ 208. I disagree. As I explained above (*see supra*, § VII.B.1.a), Dr. Cooklev's conclusion is grounded in his incorrect conclusion that a person having ordinary skill in the art would not have understood the disclosures of LB-031 to apply regardless of whether an implementation uses dedicated or shared memory. Moreover, Dr. Cooklev does not explain how his conclusion that "a POSITA would be motivated **not** to use the teachings of LB-031 if they were concerned with reducing memory requirements" (Cooklev Report at ¶ 208) squares with the explicit disclosures of LB-031 that "[t]he interleaver is a

major source of complexity in VDSL,” and that the proposal allows “lower complexity implementations for profiles that do not require the full VDSL2 data rate.” LB-031 at p. 1. For at least these reasons, I disagree with Dr. Cooklev’s conclusion that a skilled artisan would not have been motivated to combine the teachings of Mazzoni with the teachings of LB-031.

128. Dr. Cooklev also disputes my statement that a skilled artisan wishing to implement the VDSL transceiver of Mazzoni would have been motivated to include the initialization message of LB-031 so that the VTU-O and VTU-R of Mazzoni could choose values for the parameters  $I$ ,  $M$ ,  $I'$  and  $M'$  that would not exceed the size of the shared memory at the selected downstream and upstream bit rates. Cooklev Report at ¶ 209. According to Dr. Cooklev, because Mazzoni discloses the use of a pre-populated table of the parameters  $I$ ,  $M$ ,  $I'$  and  $M'$ , “[t]here is no use for a message that specifies the maximum supported interleaver or deinterleaver memory size (assuming such a message is even disclosed per LB-031) because all data rate pairs and their corresponding  $I$ ,  $M$ ,  $I'$  and  $M'$  values that need to be supported are accounted for.” Cooklev Report at ¶ 210. I disagree. As explained in my Opening Report (*see* Jacobsen Opening Report at ¶ 626), one of ordinary skill would have recognized the inherent limitations of Mazzoni’s table, namely that all services would need to be identified ahead of time so that the table could be created and stored in the transceiver. The skilled artisan would also have recognized that, as of the priority date of the Family 3 patents, the teachings of LB-031 would enable the transceivers of Mazzoni to partition the shared memory between the interleaver and deinterleaver without requiring all of the possible services to be defined in advance to create the table disclosed in Mazzoni. Instead, by exchanging information about their interleaving and deinterleaving capabilities as disclosed in LB-031, the transceivers of Mazzoni could easily determine an appropriate allocation of the available shared memory to the

interleaver and deinterleaver for a variety of services. The resulting transceiver would have the advantage of being more flexible and “future-proof” than the transceiver described in Mazzoni.

129. At paragraph 211, Dr. Cooklev concedes that LB-031 discloses the “exchange of maximum supported memory sizes.” Dr. Cooklev then provides an example that, according to him, indicates that the teachings of LB-031 are “incompatible” with those of Mazzoni. Cooklev Report at ¶ 211. Dr. Cooklev argues that “[i]f the Mazzoni VTU-O received a message indicating that the VTU-R supported a maximum downstream deinterleaver memory of 24,960 bytes and a maximum upstream interleaver memory of 10,860 bytes, this information would be useless to the VTU-O” because “it already has the information necessary to support the service for which both transceivers have been preconfigured at the time of installation,” and “neither the VTU-O or VTU-R would actually be capable of simultaneously supporting both maximum interleaver and deinterleaver sizes at the same time because the total memory size of the Mazzoni transceivers is only 26,890 bytes. . . .” Cooklev Report at ¶ 211. Dr. Cooklev’s hypothetical example assumes that the skilled artisan would merely add the message of LB-031 to the transceiver of Mazzoni without any modification, because his point appears to be that the memory described in Mazzoni is not large to accommodate the transmission parameters described in LB-031. This is specious, as it would be trivial to one of ordinary skill in the art to select a different-sized memory for the interleaver/deinterleaver pair. As I explained above (*see, e.g., supra*, § VII.A.3) and in my Opening Report (*see* Jacobsen Opening Report at ¶ 626), the skilled artisan would have recognized the inherent limitations of Mazzoni’s table, and that the teachings of LB-031 would enable the transceivers of Mazzoni to partition the shared memory between the interleaver and deinterleaver without requiring all of the possible services to be defined in advance to create the table disclosed in Mazzoni.

130. Therefore, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that a skilled artisan would have been motivated to combine the disclosures of Mazzoni and LB-031 as recited in the asserted claims of the Family 3 patents.

**2. Claim 1 of the '048 Patent**

131. It remains my opinion that LB-031 in combination with Mazzoni renders claim 1 of the '048 patent obvious.

132. I incorporate by reference my discussion and opinion in § VII.C.1 regarding why a person having ordinary skill in the art would have been motivated to combine the disclosures of LB-031 and Mazzoni.

**a. 1[a]. "A system that allocates shared memory"**

133. I explained above why I disagree with Dr. Cooklev's opinion that LB-031 does not disclose "[a] system that allocates shared memory." *See supra*, § VII.B.1.a.

134. Dr. Cooklev purports to dispute that Mazzoni discloses a system that allocates shared memory, yet his argument does not actually dispute that the transceiver of Mazzoni uses shared memory. Cooklev Report at ¶¶ 217-18. Instead, Dr. Cooklev's argument goes to the other limitations of claim 1. For example, Dr. Cooklev argues that "Mazzoni does not disclose exchanging any messages at all that include information about interleaving or deinterleaving parameters" and "Mazzoni does not disclose a transceiver that (1) transmits or receives a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver; (2) determining an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within the shared memory; and (3) allocating a first number of bytes of the shared memory to the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the interleaver does not

exceed the maximum number of bytes in the message.” Cooklev Report at ¶ 217-18 (internal citations omitted). None of these statements supports Dr. Cooklev’s conclusion that Mazzoni does not disclose “a system that allocates shared memory.” To the extent that Dr. Cooklev elaborates on these arguments with respect to these elements, I address them below.

135. As I explained in my Opening Report (*see* Jacobsen Opening Report at ¶¶ 249-56, 260), Mazzoni explicitly discloses “shared memory” as construed by the Court, i.e., “common memory used by at least two functions, where a portion of the memory can be used by either one of the functions.” Mazzoni discloses that it provides a memory that “can be shared between the interleaving means and the deinterleaving means, and whose memory allocation can be reconfigured in accordance with the bit rate actually processed by the send/receive device (modem).” Mazzoni at col. 1:59-65. Furthermore, claim 13 of Mazzoni recites “[a] method for sending and receiving digital data and processing different bit rates from a group of predetermined bit rates, the method comprising: interleaving and deinterleaving the digital data; setting a minimum size of a shared memory based upon a maximum bit rate of the group of predetermined bit rates; assigning a first memory space of the shared memory for interleaving and a second memory space of the shared memory for deinterleaving, a size of each of the first and second memory spaces being set as a function of the bit rate actually processed by the device; performing Reed-Solomon coding and decoding for a length N of the digital data; and the interleaving providing convolutional interleaving of I branches with  $i-1$  blocks of M bytes, and the deinterleaving providing convolutional deinterleaving with  $I'$  branches of  $i'-1$  blocks of  $M'$  bytes, with I and  $I'$  being sub-multiples of N and i and  $i'$  being current relative indexes of the branches.” *Id.* at col. 10:22-42.

136. Thus, having considered Dr. Cooklev's arguments to the contrary, it remains my opinion that Mazzoni in combination with LB-031 discloses common memory used by an interleaver and a deinterleaver, where a portion of the memory can be used by either one of the two functions.

b. 1[b]. "a transceiver that is capable of"

137. Dr. Cooklev concedes that Mazzoni in combination with LB-031 discloses a transceiver. *See, e.g.*, Cooklev Report at ¶¶ 193-264.

c. 1[c]. "transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver"

138. Dr. Cooklev disputes that LB-031 in combination with Mazzoni discloses "transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver." Cooklev Report at ¶ 220-23.

139. In his discussion of LB-031 alone, Dr. Cooklev conceded that LB-031 discloses this limitation. *See* Cooklev Report at ¶¶ 90-192 (no dispute that LB-031 discloses transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver). Therefore, LB-031 in combination with Mazzoni discloses it as well, at least within the interpretation of the claim language advanced by TQ Delta in its infringement case.

140. Throughout his argument with respect to this limitation, (*see* Cooklev Report at ¶¶ 220-22), Dr. Cooklev argues, incorrectly, that I contend that the transceivers of Mazzoni exchange the parameters I, M, I' and M' during initialization. Dr. Cooklev is wrong and, in fact, acknowledges that I stated multiple times in my Opening Report that the transceivers of Mazzoni store the values of I, M, I' and M' in tables. *See, e.g.*, Cooklev Report at ¶ 221.



141. At paragraph 220, Dr. Cooklev quotes a sentence from paragraph 269 of my report: “One of ordinary skill in the art would have understood that the bit rate information, as well as capabilities of the transceiver at the other end of the system, would have to be conveyed, for example, in the form of a message during initialization, as is described in LB-031.” Cooklev Report at ¶ 220. Dr. Cooklev then states that “[t]he ‘information’ she is referring to is the parameters I, M, I’ and M’.” As the quoted sentence from my Opening Report itself indicates, Dr. Cooklev is incorrect. The “information” is, as the sentence states, “bit rate information.” *See* Jacobsen Opening Report at ¶ 269. As I explained in my Opening Report (*see id.*), Mazzoni discloses that the interleaver/deinterleaver memory has a memory allocation that “can be reconfigured in accordance with the bit rate actually processed by the send/receive device (modem).” Mazzoni, col. 1:61-65. Furthermore, Mazzoni discloses that “the sizes of the respective memory spaces assigned to the interleaving means and to the deinterleaving means” are determined “according to the bit rate of the information sent by the terminal TO (parameters I and M) and the bit rate of the information received by the terminal TO (parameters I’ and M’).” *Id.* at col. 5:24-31. Thus, the size of the memory space, determined according to the values of I, M, I’ and M’ stored in the table, is selected based on the bit rate. *Id.* at col. 6:26-30. It is that bit rate which I stated would be provided during initialization.

142. Again in paragraph 221, Dr. Cooklev responds to an argument that I did not make, namely, that the transceivers of Mazzoni exchange the values of I, M, I’ and M’ during initialization.

143. Dr. Cooklev notes that the “bit rate actually processed by the send/receive device (modem)” of Mazzoni is one of the “predetermined bit rates.” Cooklev Report at ¶ 222. I do not disagree, nor did I say anything inconsistent with this statement in my Opening Report.

Furthermore, this point is irrelevant because, as a skilled artisan would have understood, the transceivers of Mazzoni would select one of the predetermined bit rates during the initialization procedure, based on the conditions on the subscriber line. Mazzoni distinguishes between “symmetrical services” and “asymmetrical services.” *See, e.g.*, Mazzoni at col. 3:62-4:14. As an example, Mazzoni contemplates six symmetrical services and six asymmetrical services. *Id.* One of Mazzoni’s objectives is “to provide such an architecture which is adaptable, particularly in terms of the memory capacity of the interleaving and deinterleaving means, to suit a number of different bit rates selected from a predetermined group of bit rates.” *Id.* at col. 1:54-58. As a person having ordinary skill would have understood from these disclosures, the “service actually provided by the operator,” (Mazzoni at col. 6:55-59), would be either the “symmetrical service” or the “asymmetrical service,” and the “bit rate actually processed by the send/receive device (modem)” would be one of the predetermined bit rates defined for, respectively, either the “symmetrical” or “asymmetrical” services. The bit rate actually processed would be determined during initialization on the basis of the capabilities of the transceivers, at least some of which would have to be conveyed, for example, in the form of a message during initialization.

144. Dr. Cooklev asserts that “LB-031’s exchange of interleaver and deinterleaver capabilities would be useless and incompatible with Mazzoni.” As I explained above (*see supra*, § VII.C.1), I disagree. A skilled artisan would have recognized the benefits of modifying Mazzoni to incorporate the initialization message of LB-031 to obviate the need for all asymmetrical and symmetrical services to be predefined and for the transceiver to store a table indicating the values of I, M, I’ and M’ for each of the predefined bit rates.

145. Thus, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that LB-031 in combination with Mazzoni discloses transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver, within the interpretation of this limitation that has been advanced by TQ Delta in its infringement case.

- d. 1[d]. "determining an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within the shared memory"

146. Dr. Cooklev disputes that LB-031 in combination with Mazzoni discloses "determining an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within the shared memory." Cooklev Report at ¶ 224. Dr. Cooklev argues that the values of  $I$ ,  $M$ ,  $I'$  and  $M'$  are "predetermined, stored in a table, and retrieved for use at the time of installation of the transceiver." *Id.* Although Dr. Cooklev is correct that the values of  $I$ ,  $M$ ,  $I'$  and  $M'$  are stored in a table, the transceiver must still determine an amount of memory required for the interleaver to interleave a first plurality of RS coded data bytes within the shared memory. *See, e.g.*, Mazzoni at col. 7:52-8:10 ("the second address determination means MD2 must allow for the size OF of the first memory space ESM1, which is defined by the equation (1) below:  $OF = I \times (I-1) \times M/2$ , and may be stored in a register, for example. For uplink interleaving, the address of the memory MM vary in the range of 0 to OF-1."). Even if the size OF were pre-stored in a register, the transceiver would still need to read that register in order to divide the memory space of the memory MM "into a first memory space ESM1 assigned to the interleaving means MET, and a second memory space ESM2 [] assigned to the deinterleaving means MDET." Mazzoni at col. 5:64-67. This register read would itself be "determining an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within the shared memory." Implicit in Dr. Cooklev's

argument is that “determining,” as used in this claim limitation, must mean “calculating.” This interpretation is not supported by the intrinsic record, nor is it consistent with the way one of ordinary skill in the art would understand the claim language.

147. Without any citation to Mazzoni, Dr. Cooklev suggests that Mazzoni contemplates that “all necessary information is stored prior to initialization.” Cooklev Report at ¶ 225. I disagree. Although Mazzoni discloses storing the values of  $I$ ,  $M$ ,  $I'$  and  $M'$  in a table, Mazzoni does not disclose storing “all necessary information” prior to initialization, nor would a person having ordinary skill in the art expect it to do so. On the contrary, a skilled artisan would understand establishment of a DSL connection requires much more information than simply the values of  $I$ ,  $M$ ,  $I'$  and  $M'$ , and that some of this information cannot be determined until the initialization procedure is being performed.

148. Dr. Cooklev states, again, that “a POSITA would be discouraged from combining the teaching of LB-031 with the teachings of Mazzoni.” Cooklev Report at ¶ 227. As I explained above (*see supra*, § VII.C.1) and in my Opening Report (*see, e.g.*, Jacobsen Opening Report at ¶ 595), a skilled artisan would have recognized the benefits of modifying Mazzoni to incorporate initialization messages, such as the initialization message of LB-031, to obviate the need for all asymmetrical and symmetrical services to be predefined and for the transceiver to store a table indicating the values of  $I$ ,  $M$ ,  $I'$  and  $M'$  for each of the predefined bit rates.

149. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that LB-031 in combination with Mazzoni discloses determining an amount of memory required by the interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes within the shared memory.

- e. 1[e]. and 1[f] “allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate wherein the allocated memory for the interleaver does not exceed the maximum number of bytes in the message”

150. Dr. Cooklev disputes that LB-031 in combination with Mazzoni discloses “allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes in the message,” at least within the interpretation of this claim language that has been offered by TQ Delta in its infringement case. Cooklev Report at ¶ 228-30. Dr. Cooklev asserts that LB-031 does not disclose this limitation because LB-031 does not, in his opinion, disclose shared memory. Cooklev Report at ¶ 228. I explained above why I disagree with Dr. Cooklev. *See supra*, § VII.B.1.a.

151. Dr. Cooklev argues that “LB-031’s exchange of interleaver and deinterleaver capabilities is redundant to Mazzoni’s stored predefined service data rates and interleaver/deinterleaver parameters and incompatible with Mazzoni at least because the exchange of maximum supported interleaver and deinterleaver sizes per LB-031 would specify a combined amount of interleaver and deinterleaver memory that would exceed Mazzoni’s total memory size.” Cooklev Report at ¶ 229. I disagree. As I explained above, (*see supra*, § VII.C.1), it remains my opinion that a skilled artisan would have been motivated to combine the teachings of LB-031 and the teachings of Mazzoni to improve the flexibility of Mazzoni’s transceiver and to obviate the need to predefine all services.

152. Therefore, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that LB-031 and Mazzoni disclose allocating a first number of bytes of the shared

memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate.

153. Dr. Cooklev disputes that LB-031 in combination with Mazzoni discloses that the allocated memory for the interleaver does not exceed the maximum number of bytes in the message. Cooklev Report at ¶ 230. I disagree. As my Opening Report indicates, the primary basis for my opinion that LB-031 in combination with Mazzoni discloses this limitation is the content of LB-031. *See* Jacobsen Opening Report at ¶ 282. Dr. Cooklev’s focus on Mazzoni is misplaced.

154. Therefore, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that LB-031 and Mazzoni disclose wherein the allocated memory for the interleaver does not exceed the maximum number of bytes in the message, according to the interpretation of the claim advanced by TQ Delta in its infringement case.

- f. 1[g]. “allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate”

155. Dr. Cooklev concedes that LB-031 in combination with Mazzoni discloses “allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate.” *See* Cooklev Report at ¶¶ 215-30.

- g. 1[h]. “interleaving the first plurality of RS coded data bytes within the shared interleaver memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver”

156. Dr. Cooklev concedes that LB-031 in combination with Mazzoni discloses “interleaving the first plurality of RS coded data bytes within the shared interleaver memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver.” *See* Cooklev Report at ¶¶ 215-30.

- h. 1[i]. “wherein the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver”

157. Dr. Cooklev concedes that LB-031 in combination with Mazzoni discloses “wherein the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver.” *See* Cooklev Report at ¶¶ 215-30.

158. Thus, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that LB-031 in combination with Mazzoni discloses all of the limitations of claim 1 of the ’048 patent.

### **3. Claim 5 of the ’381 Patent**

159. Having considered Dr. Cooklev’s arguments to the contrary, it remains my opinion that claim 5 of the ’381 patent is rendered obvious by LB-031 in combination with Mazzoni.

160. I incorporate by reference my discussion and opinion in § VII.C.1 regarding why a person having ordinary skill in the art would have been motivated to combine the disclosures of LB-031 and Mazzoni.

- a. 5[a]. “A non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver”

161. Dr. Cooklev disputes that LB-031 in combination with Mazzoni discloses “[a] non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver.” Cooklev Report at ¶ 232. I disagree.

162. Dr. Cooklev argues that LB-031 “does not disclose the exchange of information that would be useful for allocating shared memory.” Cooklev Report at ¶ 233. As an initial matter, Dr. Cooklev conceded that LB-031 discloses “transmitting or receiving a message

during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver.” *See supra*, § VII.B.1.c. Furthermore, as I explained above, (*see, e.g., supra* § VII.B.1.a, § VII.B.1.e), LB-031 discloses allocating shared memory.

163. Dr. Cooklev also argues that the information exchanged by the VTU-O and VTU-R in LB-031 “could not be used by a Mazzoni transceiver to allocate shared memory.” As I explained above (*see supra* § VII.C.1), I disagree.

164. Dr. Cooklev appears to assert that because “one or more of the claimed functions could be implemented in hardware, and therefore would not necessarily have to be carried out through an execution of instructions stored on a non-transitory computer-readable media,” neither LB-031 nor Mazzoni discloses the preamble of claim 5. Cooklev Report at ¶ 237. I disagree. First, according to Dr. Cooklev, “a POSITA at the time of the invention had (i) a Bachelor’s degree in Electrical Engineering or a related field, and (ii) two to three years’ of experience working in DSL or other broadband communications (or a Master’s Degree in Electrical Engineering or a related field, particularly with an emphasis in the area of communications).” Cooklev Opening Infringement Report at ¶ 27. A person having the level of skill suggested by Dr. Cooklev would have understood that transceivers include hardware and software, and therefore the universe of ways to implement a transceiver as taught by LB-031 and as taught by Mazzoni extends to hardware, software, or some combination of the two. That LB-031 or Mazzoni does not explicitly refer to a particular approach does not mean that a skilled artisan would not have understood that approach to be disclosed.

165. Furthermore, with respect to Mazzoni in particular, as Dr. Cooklev stated in his discussion on written description and enablement, “a patent need not teach, and preferably omits, what is well known in the art.” Cooklev Report at ¶ 80. Thus, Dr. Cooklev agrees that



“it was not necessary [for Mazzoni] to provide a full and detailed explanation where, as here, a POSITA would know how to implement the claim.” *Id.*

166. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that LB-031 in combination with Mazzoni discloses “[a] non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver.”

- b. 5[b]. “transmitting or receiving, by the transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver”

167. Dr. Cooklev purports to dispute that LB-031 in combination with Mazzoni discloses “transmitting or receiving, by the transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver.” Cooklev Report at ¶ 241. As an initial matter, Dr. Cooklev conceded that LB-031 discloses this limitation under TQ Delta’s interpretation. *See, e.g.*, Cooklev Report at ¶¶ 90-192; *see also supra*, § VII.B.2.b. Yet Dr. Cooklev argues that LB-031 in combination with Mazzoni somehow does not disclose this limitation because (a) “Mazzoni does not disclose exchanging any messages at all that include information about interleaving or deinterleaving parameters,” (b) “Mazzoni does not describe any message specifying an amount of memory that can be allocated to an interleaver or to a deinterleaver,” and (c) “LB-031’s exchange of interleaver and deinterleaver capabilities would be useless and incompatible with Mazzoni.” Cooklev Report at ¶¶ 241-42. I disagree with Dr. Cooklev. As he acknowledged, LB-031 discloses this limitation, and therefore LB-031 in combination with Mazzoni does, too.

168. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that LB-031 in combination with Mazzoni discloses “transmitting or receiving, by the transceiver, a message during initialization specifying a maximum number of bytes of memory

that are available to be allocated to a deinterleaver,” within the interpretation of the claim language advanced by TQ Delta in its infringement case.

- c. 5[c]. “determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory”

169. Dr. Cooklev disputes that LB-031 in combination with Mazzoni discloses “determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory.” Cooklev Report at ¶¶ 243-45. Dr. Cooklev’s rebuttal refers to his arguments with respect to element 1[d]. I explained above (*see supra*, § VII.C.2.d) why I disagree with Dr. Cooklev.

170. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that LB-031 in combination with Mazzoni discloses “determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory.”

- d. 5[d] and 5[e]. “allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message”

171. Dr. Cooklev disputes that LB-031 in combination with Mazzoni discloses “allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message.” Cooklev Report at ¶¶ 246-48.

172. With respect to LB-031 alone, Dr. Cooklev’s argument is that LB-031 does not disclose shared memory. I explained above (*see, e.g., supra*, § VII.B.1.a) why I disagree with Dr. Cooklev.

173. With respect to Mazzoni, Dr. Cooklev argues that “Mazzoni does not disclose transmitting or receiving any message with interleaver or deinterleaver parameters,” and that “LB-031’s exchange of interleaver and deinterleaver capabilities is redundant to Mazzoni’s stored predefined service data rates and interleaver/deinterleaver parameters and incompatible with Mazzoni. . . .” Cooklev Report at ¶ 247. I explained above (*see, e.g., supra*, § VII.C.1) why I disagree with Dr. Cooklev’s opinion. A skilled artisan wishing to implement the VDSL transceiver of Mazzoni would have recognized the inherent limitations of Mazzoni’s table and the desirability of including the initialization message of LB-031 so that the VTU-O and VTU-R of Mazzoni could choose values for the parameters I, M, I’ and M’ that would not exceed the size of the shared memory at the selected downstream and upstream bit rates without the need to define all of the services in advance.

174. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that LB-031 in combination with Mazzoni discloses “allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message,” within the interpretation of this claim limitation advanced by TQ Delta in its infringement case.

- e. 5[f]. “allocating, in the transceiver, a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate”

175. Dr. Cooklev concedes that LB-031 in combination with Mazzoni discloses “allocating, in the transceiver, a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate.” Cooklev Report at ¶¶ 231-48.

- f. 5[g]. “deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver”

176. Dr. Cooklev concedes that LB-031 in combination with Mazzoni discloses “deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver.” Cooklev Report at ¶¶ 231-48.

- g. 5[h]. “wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver”

177. Dr. Cooklev concedes that LB-031 in combination with Mazzoni discloses “wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver.” Cooklev Report at ¶¶ 231-48.

178. Thus, having considered Dr. Cooklev’s arguments to the contrary, it remains my opinion that LB-031 in combination with Mazzoni renders claim 5 of the ’381 patent obvious.

#### **4. Claim 13 of the ’882 patent**

179. Having considered Dr. Cooklev’s arguments to the contrary, it remains my opinion that LB-031 in combination with Mazzoni renders claim 13 of the ’882 patent obvious, as I explain below.

180. I incorporate by reference my discussion and opinion in § VII.C.1 regarding why a person having ordinary skill in the art would have been motivated to combine the disclosures of LB-031 and Mazzoni.

- a. 13[a]. “A system that allocates shared memory”

181. Dr. Cooklev disputes that LB-031 in combination with Mazzoni discloses “[a] system that allocates shared memory.” Cooklev Report at ¶ 250. I explained above (*see supra*, § VII.C.2.a) why I disagree with Dr. Cooklev.

182. Thus, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that LB-031 in combination with Mazzoni discloses a system that allocates shared memory.

b. 13[b]. "a transceiver that performs"

183. Dr. Cooklev concedes that LB-031 in combination with Mazzoni discloses a transceiver. *See* Cooklev Report at ¶¶ 249-54.

c. 13[c] through 13[i]

184. Dr. Cooklev adopts wholesale his arguments with respect to claim 5 of the '381 patent and claim 1 of the '048 patent as his argument with respect to elements 13[c] through 13[i] of claim 13 of the '882 patent, and does not make any additional arguments or express any additional opinions. Cooklev Report at ¶¶ 251-54. I do the same with respect to these claim elements. *See supra*, §§ VII.C.2, VII.C.3.b-VII.C.3.g.

185. Thus, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that LB-031 in combination with Mazzoni discloses all of the limitations of claim 13 of the '882 patent and, therefore, that LB-031 in combination with Mazzoni renders claim 13 obvious.

**5. Claim 19 of the '473 Patent**

186. Having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that LB-031 in combination with Mazzoni renders claim 19 of the '473 patent obvious.

187. I incorporate by reference my discussion and opinion in § VII.C.1 regarding why a person having ordinary skill in the art would have been motivated to combine the disclosures of LB-031 and Mazzoni.

a. 19[a]. “An apparatus comprising”

188. Dr. Cooklev concedes that LB-031 in combination with Mazzoni discloses an apparatus. *See* Cooklev Report at ¶¶ 255-64.

b. 19[b]. “a multicarrier communications transceiver that is configured to perform an interleaving function associated with a first latency path and perform a deinterleaving function associated with a second latency path”

189. Dr. Cooklev concedes that LB-031 in combination with Mazzoni discloses “a multicarrier communications transceiver that is configured to perform an interleaving function associated with a first latency path and perform a deinterleaving function associated with a second latency path.” *See* Cooklev Report at ¶¶ 255-64.

c. 19[c]. “the multicarrier communications transceiver being associated with a memory”

190. Dr. Cooklev concedes that LB-031 in combination with Mazzoni discloses a multicarrier communications transceiver that is associated with a memory. *See* Cooklev Report at ¶¶ 255-64.

d. 19[d]. “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver”

191. Dr. Cooklev disputes that LB-031 in combination with Mazzoni discloses that “the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.” Cooklev Report at ¶ 256.

192. Dr. Cooklev does not dispute that LB-031 discloses a message received during an initialization of the transceiver. *See* Cooklev Report at ¶¶ 256-60. He disputes only that LB-031 discloses shared memory and the allocation of the shared memory between the interleaving function and the deinterleaving function based on that message. *See* Cooklev Report at ¶¶ 256,

171-88. As I explained above (*see, e.g., supra*, § VII.B.1.a), Dr. Cooklev’s opinion is based on the erroneous assumption that a skilled artisan would not have understood the disclosures of LB-031 to apply regardless of whether an implementation uses dedicated or shared memory for interleaving and deinterleaving. As I explained in my Opening Report, one of ordinary skill in the art would have understood that LB-031 discloses allocating the memory between an interleaving function and a deinterleaving function based on the interleaver delay exchanged during initialization. Jacobsen Opening Report at ¶¶ 337-38.

193. Dr. Cooklev’s rebuttal focuses on Mazzoni and the fact that the parameters I, M, I’ and M’ are predefined and stored in a table. Cooklev Report at ¶¶ 257-59. I explained in my Opening Report and above that a skilled artisan would have recognized the need to define all of the services ahead of time and store all of the values of I, M, I’ and M’ in a table to be a disadvantage of Mazzoni because it would limit the flexibility of the implementation.

194. Dr. Cooklev repeats his argument that “LB-031’s exchange of interleaver and deinterleaver capabilities is redundant to Mazzoni’s stored predefined service data rates and interleaver/deinterleaver parameters and incompatible with Mazzoni at least because the exchange of maximum supported interleaver and deinterleaver sizes per LB-031 would specify a combined amount of interleaver and deinterleaver memory that would exceed Mazzoni’s total memory size.” Cooklev Report at ¶ 260. I disagree. As I explained above, (*see supra*, § VII.C.1), it remains my opinion that a skilled artisan would have been motivated to combine the teachings of LB-031 and the teachings of Mazzoni to improve the flexibility of Mazzoni’s transceiver and to obviate the need to predefine all services.

195. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that LB-031 in combination with Mazzoni discloses “wherein the memory is allocated

between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.”

- e. 19[e]. “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message”

196. Dr. Cooklev disputes that LB-031 in combination with Mazzoni discloses that “at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.” Cooklev Report at ¶¶ 261-64.

197. Dr. Cooklev’s argues that “Mazzoni does not disclose exchanging any messages at all that include information about interleaving or deinterleaving parameters (or any other information upon which interleaver or deinterleaver memory allocations could be based).” Cooklev Report at ¶ 263. I disagree. As I explained in my Opening Report (*see* Jacobsen Opening Report at ¶ 344), Mazzoni discloses that the interleaver/deinterleaver memory has a memory allocation that “can be reconfigured in accordance with the bit rate actually processed by the send/receive device (modem).” Mazzoni, col. 1:61-65. Furthermore, Mazzoni discloses that “the sizes of the respective memory spaces assigned to the interleaving means and to the deinterleaving means” are determined “according to the bit rate of the information sent by the terminal TO (parameters I and M) and the bit rate of the information received by the terminal TO (parameters I’ and M’).” *Id.* at col. 5:24-31. As a skilled artisan would have understood, the bit rate of the information would be determined during initialization on the basis of messages transmitted by the two transceivers.

198. Furthermore, and as I explained in my Opening Report (*see, e.g.*, Jacobsen Opening Report at § IX.B.7) and above (*see supra*, § VII.C.1), a skilled artisan would have been motivated to modify the transceiver of Mazzoni to incorporate the initialization message of LB-



031 to avoid the need to define all services to be provided by Mazzoni's transceiver in advance. As a result of this combination, the transceivers of Mazzoni would use the initialization messages of LB-031 to exchange capabilities such as, for example, maximum bit rate and the minimum interleaver delay. LB-031 at p. 4. Based on the minimum interleaver delay, the transceivers of Mazzoni would then be able to determine the minimum amount of memory required to support the target delay. LB-031 at p. 2. Based on this determination, the transceivers of Mazzoni would divide "[t]he memory space of the memory MM . . . into a first memory space ESM1 assigned to the interleaving means MET, and a second memory space ESM2 [] assigned to the deinterleaving means MDET." Mazzoni at col. 5:64-67.

199. Furthermore, Mazzoni describes that the second addressing determination means (for the deinterleaver) "must allow for the size OF of the first memory space ESM1" (i.e., for interleaving). Mazzoni further discloses that the size OF of the first memory space ESM1 is defined as  $OF = I \times (I-1) \times M/2$ . Thus, a skilled artisan would understand that depending on the values of the parameters I and M, which, per LB-031, would be exchanged during initialization, at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time based on the messages exchanged during initialization. Consequently, in combination, LB-031 and Mazzoni disclose that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.

200. Thus, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that LB-031 in combination with Mazzoni discloses "wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one

particular time depending on the message.” In addition, it remains my opinion that LB-031 in combination with Mazzoni discloses all of the limitations of claim 19 of the ’473 patent.

**D. Fadavi-Ardekani in Combination With ITU-T Recommendation G.993.1 Renders the Asserted Claims Obvious**

201. As explained below, having considered Dr. Cooklev’s arguments to the contrary, it remains my opinion that Fadavi-Ardekani, in combination with G.993.1 renders obvious each of claim 1 of the ’048 patent, claim 5 of the ’381 patent, claim 13 of the ’882 patent, and claim 19 of the ’473 patent.

202. Dr. Cooklev notes that Fadavi-Ardekani was considered during prosecution of U.S. Patent No. 7,831,890 (“the ’890 patent”). Cooklev Report at ¶ 265. As I explained in my Opening Report (*see* Jacobsen Opening Report at ¶ 139), the Examiner found, for example, that Fadavi-Ardekani teaches methods and systems for “sharing resources in a transceiver” comprising “allocating a first portion of shared memory to a first latency path (i.e., 16 Kbytes is allocated for interleave, lines 25-30 in column 7) and allocating a second portion of the shared memory to a second latency path (i.e., 4 Kbytes is allocated for deinterleave, lines 25-30 in column 7).” 12/9/2009 Office Action in App. No. 11/246,163 at 14, 16, 18-19. The Examiner also found that Fadavi-Ardekani teaches transmitting or receiving “information that is used to determine a maximum amount of shared memory that can be allocated.” *Id.* at 15, 20. Finally, the Examiner found that Fadavi-Ardekani also teaches that the first latency path may include an interleaver and the second latency path may include either a second interleaver or a deinterleaver. *Id.* at 16, 19.

**1. Claim 1 of the '048 Patent**

203. Having considered Dr. Cooklev's arguments to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 renders claim 1 of the '048 patent obvious.

a. 1[a]. "A system that allocates shared memory"

204. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.993.1 discloses "[a] system that allocates shared memory." Cooklev Report at ¶¶ 271-75. Specifically, he contends that the Interleaver/De-Interleaver Memory (IDIM) of Fadavi-Ardekani is not "shared memory" and that the disclosure that the IDIM is used in a "ping-pang fashion" does not indicate that the IDIM is "shared memory." Cooklev Report at ¶¶ 271, 274.

205. Dr. Cooklev's argument appears to be that no portion of the IDIM of Fadavi-Ardekani is ever used at one time by an interleaver and at another time by a deinterleaver, i.e., that although Fadavi-Ardekani discloses a single IDIM, it actually provides dedicated interleaver memory and dedicated deinterleaver memory. I disagree, and I see nothing in Fadavi-Ardekani to suggest that there is any pre-set, immovable boundary between the portion of the IDIM used for interleaving and the portion of the IDIM used for deinterleaving. As the Examiner of the '890 patent's application found, Fadavi-Ardekani discloses shared memory as recited in the Family 3 patents' claims. 12/9/2009 Office Action in App. No. 11/246,163 at 15, 20. *See also, e.g.,* 9/28/2010 Office Action in App. No. 13/567,261 ('473 patent) at pp. 3-4 (stating that Fadavi-Ardekani discloses shared memory); 1/6/2001 Office Action in App. No. 12/901,699 ('048 patent) at pp. 6-9 (finding Fadavi-Ardekani to disclose all limitations of claims except "transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to an interleaver").

206. Furthermore, as Dr. Cooklev acknowledges (see Cooklev Report at ¶ 275), Fadavi-Ardekani discloses an “optimal implementation” that “utilizes the same memory for receive data and transmit data.” Fadavi-Ardekani at col. 7:25-27. This implementation is capable of supporting “a standard ADSL session at full interleave depth,” and “[w]ith a lesser interleave depth, additional sessions may be supported with the same size buffer.” *Id.* at col. 7:25-32 (emphasis added). As a skilled artisan would have understood, this disclosure means that the memory is flexibly allocated to different interleaving and deinterleaving functions based on the number of sessions and the interleave depth, which is incompatible with Dr. Cooklev’s suggestion that the IDIM provides, in effect, dedicated memory for interleaving and dedicated memory for deinterleaving. Consequently, the IDIM of Fadavi-Ardekani is common memory used by at least two functions, where a portion of the memory can be used by either one of the functions, and is, therefore, “shared memory.”

207. Without any support, Dr. Cooklev asserts that “[t]he optimal implementation [disclosed in Fadavi-Ardekani] is incompatible with the DSL standards.” Cooklev Report at ¶ 275. On the contrary, Fadavi-Ardekani indicates that the optimal implementation is, in fact, compatible with at least T1.413-1998 (also known as T1.413 Issue 2). For example, Fadavi-Ardekani explains that “the central office of an ADSL communication system needs to support multiple ADSL lines,” and that “[t]he invention provides an Asymmetric Digital Subscriber Line (ADSL) transceiver that manages multiple asynchronous ADSL sessions. . . .” Fadavi-Ardekani at col. 2:47-64. Nothing in Fadavi-Ardekani suggests that the optimal implementation would be in any way “incompatible with the DSL standards” as Dr. Cooklev states.

208. Thus, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses a system that allocates shared memory.

b. 1[b]. "a transceiver that is capable of"

209. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses a transceiver. Cooklev Report at ¶¶ 271-80.

c. 1[c]. "transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to allocated to an interleaver"

210. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses "transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to allocated to an interleaver." Cooklev Report at ¶¶ 271-80.

d. 1[d]. "determining an amount of memory required by the interleaver to interleave a first plurality of Reed-Solomon (RS) coded data bytes within the shared memory"

211. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses "determining an amount of memory required by the interleaver to interleave a first plurality of Reed-Solomon (RS) coded data bytes within the shared memory." Cooklev Report at ¶¶ 271-80.

e. 1[e] and 1[f]. "allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes specified in the message"

212. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.993.1 discloses "allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first

rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes specified in the message.” Cooklev Report at ¶¶ 276-79.

213. In paragraph 276, Dr. Cooklev once again asserts, without any support, that “ADSL and G.Lite-compliant modems of that era” used only dedicated memory for interleaving and deinterleaving. I explained above (*see supra*, § VII.A.2) why I disagree with this assertion.

214. With respect to Fadavi-Ardekani, Dr. Cooklev argues that “no portion of the IDIM set aside for use [sic] the interleaving function will ever be allocated for use by the deinterleaving function, and vice versa,” and that “there is no scenario where unused interleaving memory will be allocated for use by the deinterleaver, and vice versa.” Cooklev Report at ¶ 277. I disagree. As I explained in my Opening Report and above (*see supra*, § VII.D.1.a), Fadavi-Ardekani indicates that the optimal implementation allows the shared memory to be allocated flexibly for interleaving and deinterleaving for multiple sessions.

215. Dr. Cooklev concedes in paragraph 278 of his report that Fadavi-Ardekani “teach[es] that ‘with a lesser depth, additional sessions may be supported with the same size buffer,’ and ‘[w]ith a larger buffer, additional session[s] may be supported,’” yet he then concludes that “this does not suggest that Fadavi allocates shared memory.” On the contrary, allocating shared memory is exactly what it suggests. The Court construed “shared memory” as “common memory used by at least two functions, where a portion of the memory can be used by either one of the functions.” Fadavi-Ardekani discloses that the “headend ADSL transceiver of the invention implements a buffering and scheduling scheme such that various transceiver components operate seamlessly . . . and share memory.” Fadavi-Ardekani at col. 9:10-13. In addition, “the same memory may be used by each of multiple ADSL sessions and by both transmit processes and receive processes,” which allows “a lesser number of transceivers, each

transceiver utilizing a lesser amount of memory . . . to implement an ADSL communication system according to the invention.” *Id.* at col. 9:18-23.

216. Furthermore, Dr. Cooklev concedes that “Fadavi uses pre-determined amounts of memory *per session*.” Cooklev Report at ¶ 278 (emphasis added). As a skilled artisan would have understood, the amount of memory needed for interleaving and deinterleaving can change from session to session depending on the selected interleaving parameters. Consequently, I disagree with Dr. Cooklev’s statement that the disclosures of Fadavi-Ardekani “preclude[] any need to use the content of the O-MSG2 message to allocate memory.” Cooklev Report at ¶ 278.

217. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses “allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes specified in the message,” at least within the interpretation of the claim language advanced by TQ Delta in its infringement case.

- f. 1[g]. “allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate”

218. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.993.1 discloses “allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate.” Cooklev Report at ¶ 280. Dr. Cooklev refers to his argument with respect to elements 1[e] and 1[f]. *Id.* I explained above (*see supra*, § VII.D.1.e) why I disagree with Dr. Cooklev’s position, and I incorporate that discussion and my opinion here.

219. Thus, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses "allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate."

- g. 1[h]. "interleaving the first plurality of RS coded data bytes within the shared memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver"

220. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses "interleaving the first plurality of RS coded data bytes within the shared memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver." Cooklev Report at ¶¶ 271-80.

- h. 1[i]. "wherein the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver"

221. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses "wherein the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver." Cooklev Report at ¶¶ 271-80.

222. Thus, having considered Dr. Cooklev's argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses all of the limitations of claim 1 of the '048 patent.

## **2. Claim 5 of the '381 Patent**

223. Having considered Dr. Cooklev's argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 renders claim 5 of the '381 patent obvious.

- a. 5[a]. "A non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a



processor, cause to be performed a method for allocating shared memory in a transceiver”

224. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.993.1 discloses “[a] non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver.” Cooklev Report at ¶ 281. Dr. Cooklev’s argument is that Fadavi-Ardekani does not disclose “shared memory,” and therefore it cannot disclose element 5[a]. *Id.*

225. I disagree. As I explained above (*see supra*, § VII.D.1.a), Fadavi-Ardekani discloses “shared memory,” i.e., “common memory used by at least two functions, where a portion of the memory can be used by either one of the functions.”

226. Furthermore, with respect to Fadavi-Ardekani in particular, as Dr. Cooklev stated in his discussion on written description and enablement, “a patent need not teach, and preferably omits, what is well known in the art.” Cooklev Report at ¶ 80. Thus, Dr. Cooklev agrees that “it was not necessary [for Fadavi-Ardekani] to provide a full and detailed explanation where, as here, a POSITA would know how to implement the claim.” *Id.*

227. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses “[a] non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver.”

- b. 5[b]. “transmitting or receiving, by the transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver”

228. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses “transmitting or receiving, by the transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver,” within the interpretation of this limitation advanced by TQ Delta in its infringement case. Cooklev Report at ¶¶ 281-83.

- c. 5[c]. “determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory”

229. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses “determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory.” Cooklev Report at ¶¶ 281-83.

- d. 5[d] and 5[e]. “allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message”

230. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.993.1 discloses “allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message.” Cooklev Report at ¶ 282. Dr. Cooklev cites his argument with respect to elements 1[e] and 1[f] of the ’048 patent and argues, again, that neither Fadavi-Ardekani nor G.993.1 discloses “shared memory.” *Id.*

231. I disagree. As I explained above (*see supra*, §§ VII.D.1.a, VII.D.1.e), Fadavi-Ardekani discloses shared memory, and Fadavi-Ardekani in combination with G.993.1 discloses elements 1[e] and 1[f], which are the same as elements 5[d] and 5[e] except for reciting an interleaver instead of a deinterleaver. Furthermore, Dr. Cooklev does not dispute that G.993.1 discloses the message of claim 5, i.e., a message transmitted or received during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver. *See* Cooklev Report at ¶¶ 265-301.

232. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses “allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message,” as that limitation is interpreted by TQ Delta in its infringement case.

- e. 5[f]. “allocating, in the transceiver, a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate”

233. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.993.1 discloses “allocating, in the transceiver, a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate.” Cooklev Report at ¶ 283. Dr. Cooklev merely references his argument with respect to elements 1[e] and 1[f]. *Id.* I explained above (*see supra*, § VII.D.1.e) why I disagree with Dr. Cooklev.

234. Thus, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses “allocating, in the

transceiver, a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate.”

- f. 5[g]. “deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver”

235. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses “deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver.” Cooklev Report at ¶¶ 281-83.

- g. 5[h]. “wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver”

236. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses “wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver.” Cooklev Report at ¶¶ 281-83.

237. Thus, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses all of the limitations of claim 5 of the ’381 patent.

### **3. Claim 13 of the ’882 patent**

238. Having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 renders claim 13 of the ’882 patent obvious.

- a. 13[a]. “A system that allocates shared memory”

239. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.993.1 discloses “[a] system that allocates shared memory.” Cooklev Report at ¶ 284. Dr. Cooklev

merely references his argument with respect to element 1[a] of the '048 patent. *Id.* I explained above (*see supra*, § VII.D.1.a) why I disagree with Dr. Cooklev.

240. Thus, having considered Dr. Cooklev's argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses a system that allocates shared memory.

b. 13[b]. "a transceiver"

241. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses a transceiver. Cooklev Report at ¶¶ 284-86.

c. 13[c]. "transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver"

242. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses "transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver," at least within the interpretation of this claim language advanced by TQ Delta in its infringement reports. Cooklev Report at ¶¶ 284-86.

d. 13[d]. "determining an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory"

243. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses "determining an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory." Cooklev Report at ¶¶ 284-86.

- e. 13[e], and 13[f]. “allocating a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for reception at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message”

244. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.993.1 discloses “allocating a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for reception at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message.” Cooklev Report at ¶ 285. Dr. Cooklev merely references his argument with respect to elements 1[e] and 1[f] of the ’048 patent. *Id.* I explained above (*see supra*, § VII.D.1.e) why I disagree with Dr. Cooklev.

245. Thus, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses “allocating a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for reception at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message,” at least within TQ Delta’s interpretation of this claim language in its infringement case.

- f. 13[g]. “allocating a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate”

246. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.993.1 discloses “allocating a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate.” Cooklev Report at ¶¶ 286. Dr. Cooklev merely references his argument with respect to elements 1[e] and 1[f] of the ’048 patent. *Id.* I explained above (*see supra*, § VII.D.1.e) why I disagree with Dr. Cooklev.

247. Thus, having considered Dr. Cooklev's argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses "allocating a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate."

- g. 13[h]. "deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver"

248. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses "deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver." Cooklev Report at ¶¶ 284-86.

- h. 13[i]. "wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver"

249. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses "wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver." Cooklev Report at ¶¶ 284-86.

250. Thus, having considered Dr. Cooklev's argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses all of the limitations of claim 13 of the '882 patent.

#### **Claim 19 of the '473 Patent**

251. Having considered Dr. Cooklev's arguments to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 renders claim 19 of the '473 patent obvious.

- a. 19[a]. “An apparatus comprising”

252. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses an apparatus. Cooklev Report at ¶¶ 287-94.

- b. 19[b]. “a multicarrier communications transceiver that is configured to perform an interleaving function associated with a first latency path and perform a deinterleaving function associated with a second latency path”

253. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses “a multicarrier communications transceiver that is configured to perform an interleaving function associated with a first latency path and perform a deinterleaving function associated with a second latency path.” Cooklev Report at ¶¶ 287-94.

- c. 19[c]. “the multicarrier communications transceiver being associated with a memory”

254. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.993.1 discloses that the multicarrier communications transceiver is associated with a memory. Cooklev Report at ¶¶ 287-94.

- d. 19[d]. “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver”

255. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.993.1 discloses that “the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.” Cooklev Report at ¶ 287. Dr. Cooklev contends that in Fadavi-Ardekani, “[t]he interleaver is assigned a pre-determined amount of memory[,], the size of which ‘is derived by multiplying the maximum codeword length by the maximum interleaver depth.’” *Id.* at ¶ 288 (quoting Fadavi-Ardekani at col. 7:5-10). I disagree. The calculation to which Dr. Cooklev refers is to determine the total amount of memory to provide in an implementation. Immediately after



disclosing how to determine the total amount of memory to provide, and as Dr. Cooklev acknowledges elsewhere in his report (*see* Cooklev Report at ¶ 275), Fadavi-Ardekani discloses an “optimal implementation” that “utilizes the same memory for receive data and transmit data.” Fadavi-Ardekani at col. 7:25-27. This implementation is capable of supporting “a standard ADSL session at full interleave depth,” and “[w]ith a lesser interleave depth, additional sessions may be supported with the same size buffer.” *Id.* at col. 7:25-32 (emphasis added). As a skilled artisan would have understood, this disclosure means that the memory is flexibly allocated to different interleaving and deinterleaving functions based on the number of sessions and the interleave depth. Consequently, Fadavi-Ardekani discloses that the memory is allocated between the interleaving function and the deinterleaving function. And, as I explained in my Opening Report (*see, e.g.*, Jacobsen Opening Report at ¶¶ 447-48), to perform the allocation of memory between the interleaving functions and deinterleaving functions, the transceiver of Fadavi-Ardekani would use the parameters specified in the O-MSG2 and R-MSG2 messages of G.993.1.

256. Without any support, Dr. Cooklev asserts that “a POSITA would understand G.993.1 to provide for dedicated downstream memories in each transceiver and separate, dedicated upstream memories in each transceiver,” which he contends was “consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems, including the LB-031 modem.” Cooklev Report at ¶ 290. I disagree. As I have explained (*see supra*, § VII.A.2), Dr. Cooklev’s assertions that prior art implementations always and only used dedicated interleaver memory and dedicated deinterleaver memory are unsupported and speculative.

257. Dr. Cooklev also argues that “the IDIM [of Fadavi-Ardekani] is not allocated between the interleaving and deinterleaving functions.” Cooklev Report at ¶ 291. I disagree. As I have explained (*see, e.g., supra*, § VII.D.1.a), and as Dr. Cooklev acknowledges elsewhere in his report (*see, e.g.,* Cooklev Report at ¶ 275), Fadavi-Ardekani discloses an “optimal implementation” that “utilizes the same memory for receive data and transmit data.” Fadavi-Ardekani at col. 7:25-27. This implementation is capable of supporting “a standard ADSL session at full interleave depth,” and “[w]ith a lesser interleave depth, *additional sessions may be supported with the same size buffer.*” *Id.* at col. 7:25-32 (emphasis added). As a skilled artisan would have understood, this disclosure means that the memory is flexibly allocated to different interleaving and deinterleaving functions based on the number of sessions and the interleave depth. Consequently, Fadavi-Ardekani discloses that the memory is allocated between the interleaving function and the deinterleaving function.

258. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses that “the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.”

- e. 19[e]. “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message”

259. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.993.1 discloses that “at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.” Cooklev Report at ¶¶ 292-94.

260. Once again, Dr. Cooklev contends that “there is no situation where a portion of the memory assigned to the interleaving function may be allocated to the deinterleaving

function and vice versa.” Cooklev Report at ¶ 292. I disagree. As I explained in my Opening Report and above (*see supra*, § VII.D.1.a), Fadavi-Ardekani indicates that the optimal implementation allows the shared memory, which sized to accommodate the maximum codeword length and the maximum interleaver depth for one session, to be allocated flexibly for interleaving and deinterleaving for multiple sessions using “a lesser interleave depth.” Fadavi-Ardekani at col. 6:66-7:33.

261. Dr. Cooklev argues that because I explained that “G.993.1 discloses that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time,” I did not address the second “wherein” clause of claim 19. Cooklev Report at ¶ 293 (quoting Jacobsen Opening Report at ¶ 452). On the contrary, and as I explained in my Opening Report (*see* Jacobsen Opening Report at ¶¶ 447-48), the VDSL transceivers described in G.993.1 are capable of sending messages during initialization, specifying communications parameters, including interleaver and deinterleaver settings and capabilities, including R-MSG2, sent by the VTU-R, that “transmits information about [the connection’s] bit allocation capabilities and several other features,” including the “Maximal interleaver memory,” expressed in bytes, and O-MSG2, transmitted by the VTU-O, which contains the field “Maximum interleaver delay,” expressed in milliseconds. I explained that a person having ordinary skill in the art would have understood as of the Family 3 patents’ priority date that because the interleaver delay is a function of the bit rate and interleaver depth, O-MSG2 specifies parameters that the VTU-O can use to allocate memory between an interleaver and a deinterleaver. It also discloses the VTU-R receiving a message during initialization (i.e., O-MSG2) that the transceiver can use to allocate memory between an interleaver and a deinterleaver (i.e., the VTU-O’s interleaver). *Id.* These disclosures indicate

that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.

262. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.” Accordingly, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.993.1 discloses all of the limitations of claim 19 of the ’473 patent.

#### **4. Motivation to Combine Fadavi-Ardekani and G.993.1**

263. Dr. Cooklev disputes that a skilled artisan would have been motivated to combine the teachings of Fadavi-Ardekani with the teachings of G.993.1 to arrive at claim 19 of the ’473 patent. Cooklev Report at ¶¶ 295-301.

264. Dr. Cooklev disputes that “both Fadavi and G.993.1 describe the need to allocate memory for interleaving and deinterleaving.” *Id.* at ¶ 297. Specifically, Dr. Cooklev contends that “Fadavi merely teaches providing each interleaver and deinterleaver with a dedicated amount of memory the size of which is ‘derived by multiplying the maximum codeword length by the maximum interleaver depth.’” *Id.* (quoting Fadavi-Ardekani at col. 7:6-10). On the contrary, and as I have explained, the portion of Fadavi-Ardekani Dr. Cooklev quotes is explaining how to derive the total size of the IDIM. Fadavi-Ardekani specifically contemplates that in deployment, the IDIM having the derived total size can “support a standard ADSL session at full interleave depth,” or “[w]ith a lesser interleave depth, additional sessions may be supported with the same size buffer.” Fadavi-Ardekani at col. 7:25-32 (emphasis added). *See also id.* at col. 7:3-5 (“The size of the IDIM and the interleave depth may be varied so that a different number of sessions may be supported by the transceiver of the invention.”); *id.* at col.

7:32-33 (“With a larger buffer, additional session[s] may be supported.”). Consequently, and contrary to Dr. Cooklev’s assertions, Fadavi-Ardekani does disclose the need to allocate memory for interleaving and deinterleaving.

265. Dr. Cooklev asserts that the optimal implementation described by Fadavi-Ardekani would be inoperable with G.993.1. Cooklev Report at ¶ 298. Without any citation to Fadavi-Ardekani, Dr. Cooklev argues that “Fadavi discloses that the same memory is used for receive and transmit data, alternately,” and that “the received deinterleave data will be overwritten with interleave data that must be interleaved and transmitted.” *Id.* at ¶ 299. Dr. Cooklev has mischaracterized the disclosures of Fadavi-Ardekani. The portions of Fadavi-Ardekani to which he appears to refer concern the use of the frame buffer (“FB”), not the interleave/deinterleave memory (“IDIM”), which is a separate memory. *See, e.g.*, Fadavi-Ardekani at FIG. 2. Although Fadavi-Ardekani discloses that the “sequence of operations minimizes memory requirements by allowing the [receive] data to overwrite the same memory area in the FB that is used by the [transmit] data, thereby permitting the size of the FB to be half that of a conventional transceiver,” (Fadavi-Ardekani at col. 8:4-8), I do not see any disclosure in Fadavi-Ardekani that the interleaver can overwrite deinterleave data (or vice versa). On the contrary, Fadavi-Ardekani discloses that once the IDIM memory has been allocated for interleaving and deinterleaving, “the DSP core may load new DMT frames of [receive] data to a portion of the IDIM used as de-interleaver memory while the FCI is using a portion of the IDIM as interleave memory.” *Id.* at col. 8:62-65. Thus, “the DSP core can read [transmit] data from the portion of the IDIM used as interleave memory while the FCI is accessing the portion of the IDIM used as de-interleave memory.” *Id.* at col. 8:67-9:3. Furthermore, as I explained in my Opening Report (*see, e.g.*, Jacobsen Opening Report at ¶ 450), Fadavi-Ardekani discloses that

the shared IDIM memory operates in a “ping-pang” fashion used by multiple functions, where “[a]s one area of memory is being used by a first agent, another area of memory can be used by a different agent.” Fadavi-Ardekani at col. 6:60-65.

266. Dr. Cooklev also asserts that “[a] POSITA would recognize that modifying Fadavi to use the initialization messages described in G.993.1 would add to complexity.” Cooklev Report at ¶ 300. I disagree. As I have explained, Fadavi-Ardekani discloses that the disclosed transceiver is capable of supporting “a standard ADSL session at full interleave depth,” and “[w]ith a lesser interleave depth, additional sessions may be supported with the same size buffer.” *Id.* at col. 7:25-32. As a skilled artisan would have understood, this disclosure means that the memory is flexibly allocated to different interleaving and deinterleaving functions based on, among other things, the interleave depth, which is one of the parameters conveyed by the G.993.1 initialization messages. *See* Jacobsen Opening Report at § VII.F.4.

267. Consequently, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that a skilled artisan would have been motivated to combine the teachings of Fadavi-Ardekani with the teachings of G.993.1 as claimed in the asserted claims of the Family 3 patents.

**E. Fadavi-Ardekani in Combination with G.992.2 Renders the Asserted Claims Obvious**

268. As explained below, having considered Dr. Cooklev’s arguments to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 renders obvious claim 1 of the ’048 patent, claim 5 of the ’381 patent, claim 13 of the ’882 patent, and claim 19 of the ’473 patent.

**1. Claim 1 of the '048 Patent**

269. Having considered Dr. Cooklev's argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 renders claim 1 of the '048 patent obvious.

a. 1[a]. "A system that allocates shared memory"

270. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.992.2 discloses "[a] system that allocates shared memory." Cooklev Report at ¶ 302. Dr. Cooklev's rebuttal refers to his argument with respect to element 1[a] for the combination of Fadavi-Ardekani and G.993.1. I explained above (*see supra*, § VII.D.1.a) why I disagree with Dr. Cooklev.

271. Thus, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses a system that allocates shared memory.

b. [1b]. "a transceiver that is capable of"

272. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses a transceiver. Cooklev Report at ¶¶ 302-05.

c. 1[c] "transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to allocated to an interleaver"

273. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses "transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to allocated to an interleaver, at least within TQ Delta's interpretation of this limitation in its infringement case." Cooklev Report at ¶¶ 302-05.

- d. 1[d]. “determining an amount of memory required by the interleaver to interleave a first plurality of Reed-Solomon (RS) coded data bytes within the shared memory”

274. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses “determining an amount of memory required by the interleaver to interleave a first plurality of Reed-Solomon (RS) coded data bytes within the shared memory.” Cooklev Report at ¶¶ 302-05.

- e. 1[e] and 1[f]. “allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes specified in the message”

275. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.992.2 discloses “allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes specified in the message.” Cooklev Report at ¶ 303. Dr. Cooklev’s rebuttal refers to his argument with respect to elements 1[e] and 1[f] for the combination of Fadavi-Ardekani and G.993.1. I explained above (*see supra*, § VII.D.1.e) why I disagree with Dr. Cooklev.

276. Without any support, Dr. Cooklev asserts that “a POSITA would understand G.992.2 to provide for dedicated downstream memories in each transceiver and separate, dedicated upstream memories in each transceiver,” which he contends was “consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems, including the LB-031 modem.” Cooklev Report at ¶ 304. I disagree. As I have explained (*see, e.g., supra*, § VII.A.2), Dr. Cooklev’s assertions that prior art implementations always and only used dedicated interleaver memory and dedicated deinterleaver memory are unsupported and speculative.



277. Thus, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses "allocating a first number of bytes of the shared memory to the interleaver to interleave the first plurality of Reed Solomon (RS) coded data bytes for transmission at a first rate, wherein the allocated memory for the interleaver does not exceed the maximum number of bytes specified in the message," at least within the interpretation of the claim advanced by TQ Delta in its infringement case.

- f. 1[g]. "allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate"

278. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.992.2 discloses "allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate." Cooklev Report at ¶ 305. Dr. Cooklev's rebuttal refers to his argument with respect to element 1[g] for the combination of Fadavi-Ardekani and G.993.1. I explained above (*see supra*, § VII.D.1.f) why I disagree with Dr. Cooklev.

279. Thus, having considered Dr. Cooklev's opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses "allocating a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality of RS coded data bytes received at a second data rate."

- g. 1[h]. "interleaving the first plurality of RS coded data bytes within the shared memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver"

280. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses "interleaving the first plurality of RS coded data bytes within the shared memory allocated to the interleaver and deinterleaving the second plurality of RS coded data bytes within the shared memory allocated to the deinterleaver." Cooklev Report at ¶¶ 302-05.

- h. 1[i]. “wherein the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver”

281. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses “wherein the shared memory allocated to the interleaver is used at the same time as the shared memory allocated to the deinterleaver.” Cooklev Report at ¶¶ 302-05.

282. Thus, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses all of the limitations of claim 1 of the ’048 patent.

## 2. Claim 5 of the ’381 Patent

283. Having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 renders claim 5 of the ’381 patent obvious.

- a. 5[a]. “A non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver”

284. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.992.2 discloses “[a] non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver.” Cooklev Report at ¶ 306. Dr. Cooklev’s rebuttal refers to his argument with respect to elements 1[a] and 5[a] for the combination of Fadavi-Ardekani and G.993.1. I explained above (*see supra*, §§ VII.D.1.a, VII.D.2.a) why I disagree with Dr. Cooklev.

285. Furthermore, with respect to Fadavi-Ardekani in particular, as Dr. Cooklev stated in his discussion on written description and enablement, “a patent need not teach, and preferably omits, what is well known in the art.” Cooklev Report at ¶ 80. Thus, Dr. Cooklev

agrees that “it was not necessary [for Fadavi-Ardekani] to provide a full and detailed explanation where, as here, a POSITA would know how to implement the claim.” *Id.*

286. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses “[a] non-transitory computer-readable information storage media having stored thereon instructions, that if executed by a processor, cause to be performed a method for allocating shared memory in a transceiver.”

- b. 5[b]. “transmitting or receiving, by the transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver”

287. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses “transmitting or receiving, by the transceiver, a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver,” at least within the interpretation of the claim advanced by TQ Delta in its infringement case. Cooklev Report at ¶¶ 306-08.

- c. 5[c]. “determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory”

288. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses “determining, at the transceiver, an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory.” Cooklev Report at ¶¶ 306-08.

- d. 5[d] and 5[e]. “allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message”

289. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.992.2 discloses “allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message.” Cooklev Report at ¶ 307. Dr. Cooklev’s rebuttal refers to his argument with respect to elements 1[e] and 1[f] for the combination of Fadavi-Ardekani and G.992.2. I explained above (*see supra*, § VII.E.1.e) why I disagree with Dr. Cooklev.

290. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses “allocating, in the transceiver, a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message,” at least within the interpretation of the claim language advanced by TQ Delta in its infringement case.

- e. 5[f]. “allocating, in the transceiver, a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate”

291. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.992.2 discloses “allocating, in the transceiver, a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate.” Cooklev Report at ¶ 308. Dr. Cooklev’s rebuttal refers to his argument with respect to

elements 1[e] and 1[f] for the combination of Fadavi-Ardekani and G.992.2. I explained above (*see supra*, § VII.E.1.e) why I disagree with Dr. Cooklev.

292. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses “allocating, in the transceiver, a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate.”

- f. 5[g]. “deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver”

293. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses “deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver.” Cooklev Report at ¶¶ 306-08.

- g. 5[h]. “wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver”

294. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses “wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver.” Cooklev Report at ¶¶ 306-08.

295. Therefore, having considered Dr. Cooklev’s arguments to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses all of the limitations of claim 5 of the ’381 patent.

### **3. Claim 13 of the ’882 Patent**

296. Having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 renders claim 13 of the ’882 patent obvious.

a. 13[a]. “A system that allocates shared memory”

297. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.992.2 discloses a system that allocates shared memory. Cooklev Report at ¶ 309. Dr. Cooklev’s rebuttal refers to his argument with respect to element 1[a] for the combination of Fadavi-Ardekani and G.993.1. I explained above (*see supra*, VII.D.1.a) why I disagree with Dr. Cooklev.

298. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses a system that allocates shared memory.

b. 13[b]. “a transceiver”

299. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses a transceiver. Cooklev Report at ¶¶ 309-11.

c. 13[c]. “transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver”

300. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses “transmitting or receiving a message during initialization specifying a maximum number of bytes of memory that are available to be allocated to a deinterleaver,” at least within the claim interpretation advanced by TQ Delta in its infringement reports. Cooklev Report at ¶¶ 309-11.

d. 13[d]. “determining an amount of memory required by the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes within a shared memory”

301. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses “determining an amount of memory required by the deinterleaver to deinterleave a

first plurality of Reed Solomon (RS) coded data bytes within a shared memory.” Cooklev Report at ¶¶ 309-11.

- e. 13[e], and 13[f]. “allocating a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for reception at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message”

302. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.992.2 discloses “allocating a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for reception at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message.” Cooklev Report at ¶ 310. Dr. Cooklev merely references his argument with respect to elements 1[e] and 1[f] of the ’048 patent. *Id.* I explained above (*see supra*, § VII.E.1.e) why I disagree with Dr. Cooklev.

303. Thus, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses “allocating a first number of bytes of the shared memory to the deinterleaver to deinterleave a first plurality of Reed Solomon (RS) coded data bytes for reception at a first data rate, wherein the allocated memory for the deinterleaver does not exceed the maximum number of bytes specified in the message,” at least within the interpretation of the claim advanced by TQ Delta in its infringement case.

- f. 13[g]. “allocating a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate.”

304. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.992.2 discloses “allocating a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate.” Cooklev Report at ¶ 311. Dr. Cooklev merely references his argument with respect to elements 1[e] and

1[f] of the '048 patent. *Id.* I explained above (*see supra*, § VII.E.1.e) why I disagree with Dr. Cooklev.

305. Thus, having considered Dr. Cooklev's argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses "allocating a second number of bytes of the shared memory to an interleaver to interleave a second plurality of RS coded data bytes transmitted at a second data rate."

- g. 13[h]. "deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver"

306. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses "deinterleaving the first plurality of RS coded data bytes within the shared memory allocated to the deinterleaver and interleaving the second plurality of RS coded data bytes within the shared memory allocated to the interleaver." Cooklev Report at ¶¶ 308-11.

- h. 13[i]. "wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver"

307. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses "wherein the shared memory allocated to the deinterleaver is used at the same time as the shared memory allocated to the interleaver." Cooklev Report at ¶¶ 308-11.

308. Thus, having considered Dr. Cooklev's argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses all of the limitations of claim 13 of the '882 patent.

#### **4. Claim 19 of the '473 Patent**

309. Having considered Dr. Cooklev's argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 renders claim 19 of the '473 patent obvious.



- a. 19[a]. “An apparatus comprising”

310. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses an apparatus. Cooklev Report at ¶¶ 312-15.

- b. 19[b]. “a multicarrier communications transceiver that is configured to perform an interleaving function associated with a first latency path and perform a deinterleaving function associated with a second latency path”

311. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses “a multicarrier communications transceiver that is configured to perform an interleaving function associated with a first latency path and perform a deinterleaving function associated with a second latency path.” Cooklev Report at ¶¶ 312-15.

- c. 19[c]. “the multicarrier communications transceiver being associated with a memory”

312. Dr. Cooklev concedes that Fadavi-Ardekani in combination with G.992.2 discloses that the multicarrier communications transceiver is associated with a memory. Cooklev Report at ¶¶ 312-15.

- d. 19[d]. “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver”

313. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.992.2 discloses that “the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.” Cooklev Report at ¶ 312.

314. Dr. Cooklev does not dispute that G.992.2 discloses a message received during an initialization of the transceiver, or that the messages of G.992.2 convey information used to configure interleavers and deinterleavers. Cooklev Report at ¶ 312. Dr. Cooklev’s argument is solely that “[t]he G.992.2 standard . . . does not teach using the initialization messages to

allocate memory between an interleaver and a deinterleaver.” *Id.* Without any support, Dr. Cooklev asserts that “a POSITA would understand G.992.2 to provide for dedicated downstream memories in each transceiver and separate, dedicated upstream memories in each transceiver,” which he contends was “consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems, including the LB-031 modem.” *Id.* I disagree. As I have explained (*see supra*, §§ VII.A.1, VII.A.2), Dr. Cooklev’s assertions that the standards mandated the use of dedicated interleaver and deinterleaver memory and that prior art implementations always and only used dedicated interleaver memory and dedicated deinterleaver memory are unsupported and speculative.

315. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.”

- e. 19[e]. “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message”

316. Dr. Cooklev disputes that Fadavi-Ardekani in combination with G.992.2 discloses that “at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.” Cooklev Report at ¶¶ 313-15.

317. Dr. Cooklev refers to his discussion of element 19[e] for Fadavi-Ardekani in combination with G.993.1 and contends that “Fadavi does not disclose this limitation.” Cooklev Report at ¶ 313. I disagree. As I explained in my Opening Report and above (*see supra*, VII.D.1.a), Fadavi-Ardekani indicates that the optimal implementation allows the shared memory, which is sized to accommodate the maximum codeword length and the maximum

interleaver depth for one session, to be allocated flexibly for interleaving and deinterleaving for multiple sessions using “a lesser interleave depth.” Fadavi-Ardekani at col. 6:66-7:33.

318. Dr. Cooklev argues that because I explained that because a skilled artisan would have understood that the interleaver and deinterleaver in G.992.2 are used at the same time, I did not address the second “wherein” clause of claim 19. Cooklev Report at ¶ 314 (citing Jacobsen Opening Report at ¶ 526). On the contrary, and as I explained in my Opening Report (*see* Jacobsen Opening Report at ¶¶ 522-24), the ADSL transceivers described in G.992.2 are capable of sending messages, including initialization messages, specifying communications parameters in ADSL systems. These initialization messages that contain information about the channel as well as the transceivers and their capabilities and requirements, including the RRSI field that contains ten entries, including interleave depth in codewords. As I explained, one of ordinary skill in the art would have understood that the information in these messages can be used to allocate memory between an interleaver and a deinterleaver function, at least within TQ Delta’s interpretation of the claims. These disclosures indicate that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.

319. Thus, having considered Dr. Cooklev’s opinion to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.”

320. Accordingly, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that Fadavi-Ardekani in combination with G.992.2 discloses all of the limitations of claim 19 of the ’473 patent.

## 5. Motivation to Combine Fadavi-Ardekani and G.992.2

321. Dr. Cooklev disputes that a skilled artisan would have been motivated to combine the teachings of Fadavi-Ardekani with the teachings of G.992.2 to arrive at the asserted Family 3 claims. Cooklev Report at ¶¶ 316-22.

322. As an initial matter, Dr. Cooklev did not rebut my argument that a skilled artisan would have been motivated to combine the disclosures of Fadavi-Ardekani and G.992.2 because Fadavi-Ardekani references G.1ite, which the skilled artisan would have recognized to be G.992.2. *See* Jacobsen Opening Report at ¶ 527 (“In addition, Fadavi-Ardekani references G.992.2 a number of times, confirming that one of ordinary skill in the art would naturally consider the references together.”).

323. Dr. Cooklev disputes that “both Fadavi and G.992.2 describe the need to allocate memory for interleaving and deinterleaving.” *Id.* at ¶ 318. Specifically, Dr. Cooklev contends that “Fadavi merely teaches providing each interleaver and deinterleaver with a dedicated amount of memory the size of which is ‘derived by multiplying the maximum codeword length by the maximum interleaver depth.’” *Id.* (quoting Fadavi-Ardekani at col. 7:6-10). On the contrary, and as I have explained, the portion of Fadavi-Ardekani Dr. Cooklev quotes is explaining how to derive the total size of the IDIM. Fadavi-Ardekani specifically contemplates that in deployment, the IDIM having the derived total size can “support a standard ADSL session at full interleave depth,” or “[w]ith a lesser interleave depth, additional sessions may be supported with the same size buffer.” Fadavi-Ardekani at col. 7:25-32 (emphasis added). *See also id.* at col. 7:3-5 (“The size of the IDIM and the interleave depth may be varied so that a different number of sessions may be supported by the transceiver of the invention.”); *id.* at col. 7:32-33 (“With a larger buffer, additional session[s] may be supported.”). Consequently, and

contrary to Dr. Cooklev's assertions, Fadavi-Ardekani does disclose the need to allocate memory for interleaving and deinterleaving.

324. Dr. Cooklev asserts that the optimal implementation described by Fadavi-Ardekani, would be inoperable with G.993.1. Cooklev Report at ¶ 319. Without any citation to Fadavi-Ardekani, Dr. Cooklev argues that "Fadavi discloses that the same memory is used for receive and transmit data, alternately," and that "the received deinterleave data will be overwritten with interleave data that must be interleaved and transmitted." *Id.* at ¶ 320. As I explained above, Dr. Cooklev has mischaracterized the disclosures of Fadavi-Ardekani. The portions of Fadavi-Ardekani to which he appears to refer concern the use of the frame buffer ("FB"), not the interleave/deinterleave memory ("IDIM"), which is a separate memory. *See, e.g.*, Fadavi-Ardekani at FIG. 2. Although Fadavi-Ardekani discloses that the "sequence of operations minimizes memory requirements by allowing the [receive] data to overwrite the same memory area in the FB that is used by the [transmit] data, thereby permitting the size of the FB to be half that of a conventional transceiver," (Fadavi-Ardekani at col. 8:4-8), I do not see any disclosure in Fadavi-Ardekani that the interleaver can overwrite deinterleave data (or vice versa). On the contrary, Fadavi-Ardekani discloses that once the IDIM memory has been allocated for interleaving and deinterleaving, "the DSP core may load new DMT frames of [receive] data to a portion of the IDIM used as de-interleaver memory while the FCI is using a portion of the IDIM as interleave memory." *Id.* at col. 8:62-65. Thus, "the DSP core can read [transmit] data from the portion of the IDIM used as interleave memory while the FCI is accessing the portion of the IDIM used as de-interleave memory." *Id.* at col. 8:67-9:3. Furthermore, as I explained in my Opening Report (*see, e.g.*, Jacobsen Opening Report at ¶ 450), Fadavi-Ardekani discloses that the shared IDIM memory operates in a "ping-pang"

fashion used by multiple functions, where “[a]s one area of memory is being used by a first agent, another area of memory can be used by a different agent.” Fadavi-Ardekani at col. 6:60-65.

325. Dr. Cooklev also asserts that “[a] POSITA would recognize that modifying Fadavi to use the initialization messages described in G.992.2 would add to complexity.” Cooklev Report at ¶ 321. I disagree. As I have explained, Fadavi-Ardekani discloses that the disclosed transceiver is capable of supporting “a standard ADSL session at full interleave depth,” and “[w]ith a lesser interleave depth, additional sessions may be supported with the same size buffer.” *Id.* at col. 7:25-32. As a skilled artisan would have understood, this disclosure means that the memory is flexibly allocated to different interleaving and deinterleaving functions based on, among other things, the interleave depth, which is one of the parameters conveyed by the G.992.2 initialization messages. *See* Jacobsen Opening Report at § VII.F.3.

326. Consequently, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that a skilled artisan would have been motivated to combine the teachings of Fadavi-Ardekani with the teachings of G.992.2 as claimed in the asserted claims of the Family 3 patents.

**F. Voith in Combination with LB-031 Renders Claim 19 of the ’473 Patent Obvious**

327. As explained below, having considered Dr. Cooklev’s arguments to the contrary, it remains my opinion that Voith in combination with LB-031 renders claim 19 of the ’473 patent obvious.

1. **19[a]. “An apparatus comprising”**

328. Dr. Cooklev concedes that Voith in combination with LB-031 discloses an apparatus. Cooklev Report at ¶¶ 323-40.

2. **19[b]. “a multicarrier communications transceiver that is configured to perform an interleaving function associated with a first latency path and perform a deinterleaving function associated with a second latency path”**

329. Dr. Cooklev concedes that Voith in combination with LB-031 discloses “a multicarrier communications transceiver that is configured to perform an interleaving function associated with a first latency path and perform a deinterleaving function associated with a second latency path.” Cooklev Report at ¶¶ 323-40.

3. **19[c]. “the multicarrier communications transceiver being associated with a memory”**

330. Dr. Cooklev concedes that Voith in combination with LB-031 discloses that the multicarrier communications transceiver is associated with a memory. Cooklev Report at ¶¶ 323-40.

4. **19[d]. “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver”**

331. Dr. Cooklev disputes that Voith in combination with LB-031 discloses that “the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.” Cooklev Report at ¶ 326. Specifically, Dr. Cooklev asserts that “there is no basis for concluding that Voith allocates memory between an interleaving function and a deinterleaving function.” *Id.* at ¶ 327. Dr. Cooklev’s argument is that, according to him, “[i]t does not follow from the fact that the external memory is used for both interleaving and deinterleaving that any portion of the memory is allocated *between* these functions.” *Id.* at ¶ 326 (emphasis in original). I disagree.

332. The Court’s construed “memory is allocated between the interleaving function and the deinterleaving function” as “an amount of the memory is allocated to the interleaving function and an amount of memory is allocated to the deinterleaving function.” As I explained in my Opening Report (*see* Jacobsen Opening Report at ¶ 557), Voith specifically notes that the interleaver “uses a portion of external interleave/deinterleave memory 66.” *Id.* at col. 5:65-6:1. Voith also discloses that its interleaver “arbitrates” with the deinterleaver for use of external the interleave/deinterleave memory. *Id.* at col. 6:1-4. Voith also discloses that a deinterleaver performs a deinterleave operation on the interleaved portion of the received frame. *Id.* at col. 6:24-26. Voith’s deinterleaver “makes use of external interleave/deinterleave memory 66” and “arbitrates for usage thereof” in a manner similar to the interleaver. *Id.* at col. 26-29. Thus, in accordance with the Court’s construction, and contrary to Dr. Cooklev’s assertion, in Voith, “an amount of the memory is allocated to the interleaving function and an amount of memory is allocated to the deinterleaving function.”

333. Once again, without any support, Dr. Cooklev argues that that “a POSITA reviewing Voith’s disclosure of an external interleave/deinterleave memory 66[] would understand this as disclosing that the memory includes a dedicated portion for use by interleaver 78 and a separate, dedicated portion for use by deinterleaver 90,” which he contends is “consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems, including the LB-031 modem.” Cooklev Report at ¶ 327. I disagree. As I have explained (*see supra*, § VII.A.2), Dr. Cooklev’s assertions that prior art implementations always and only used dedicated interleaver memory and dedicated deinterleaver memory are unsupported and speculative.



334. In attempting to argue that Voith does not disclose that the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver,” Dr. Cooklev suggests that I “rel[ied] on a message such as the O-B&G message described in the G993.1 standard . . . or the C-B&G message described in the G.992.2 standard. . . .” Cooklev Report at ¶ 328. He then argues that I “provide[d] no evidence that Voith teaches that ADSL transceiver 34 allocated memory 66 between the interleaver 78 and the deinterleaver 90 based on a bit-allocation message.” *Id.* On the contrary, Voith specifically refers to “the draft American National Standard for Telecommunication—Network and Customer Interfaces—Asymmetric Digital Subscriber Line (ADSL) metallic interface, T1E1.4/95-007R2, ADSL coding standard, draft, Aug. 15, 1995,” (Voith at col. 1:18-25), which a skilled artisan would have recognized as the draft of T1.413 Issue 2. Voith discloses that “[t]he bit allocation table is determined at initialization between the central office and the remote terminal based on the characteristics of the transmission link.” Voith, col. 6:9-12. Like all other ADSL standards, T1.413 Issue 2 requires the transceivers to exchange bits and gains using messages transmitted during initialization, which a skilled artisan would have understood. In my Opening Report, (*see* Jacobsen Opening Report at ¶ 558), I explained that LB-031 teaches the well-known principle that the amount of memory required to meet a particular interleaver delay requirement depends on the line data rate. *See* LB-031 at p. 4. The line data rate, in turn, depends on the number of bits assigned to each subcarrier. Therefore, Voith discloses that the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver, at least within TQ Delta’s interpretation of the claims in its infringement contentions.

335. Dr. Cooklev opines that “LB-031 at most discloses that a VTU-O (or a VTU-R) determines whether it can use all of its predetermined maximum interleaver memory or whether it has to use less of it because of the maximum capabilities of the deinterleaver on the other side of the line, are smaller.” Cooklev Report at ¶ 329. He then argues that “LB-031 does not teach that the unused portion of the interleaver memory can be allocated to the deinterleaver.” *Id.* I disagree. First, Dr. Cooklev’s conclusion presumes, without justification, that the VTU-O and VTU-R implement interleaving and deinterleaving using dedicated memories. As I explained in my Rebuttal Report (*see, e.g.*, Jacobsen Rebuttal Report at § IX), none of the VDSL standards specifies that a VTU-O or VTU-R must implement interleaving and deinterleaving using either dedicated or shared memory.

336. Second, Dr. Cooklev has ignored the Court’s construction that “memory is allocated between the interleaving function and the deinterleaving function [in accordance with a message received during an initialization of the transceiver]” means only that “an amount of the memory is allocated to the interleaving function and an amount of memory is allocated to the deinterleaving function [in accordance with a message received during an initialization of the transceiver].” Contrary to Dr. Cooklev’s assertion, the Court’s construction does not require “that the unused portion of the interleaver memory can be allocated to the deinterleaver.” Because, as I explained, Voith discloses the use of T1.413 Issue 2 ADSL, which requires the transceivers to exchange bit allocations, and LB-031 teaches that the amount of memory required to meet a particular interleaver delay requirement depends on the line data rate, which depends on the bit allocation, Voith in combination with LB-031 discloses this limitation.

337. Therefore, having considered Dr. Cooklev’s arguments to the contrary, it remains my opinion that Voith in combination with LB-031 discloses that the memory is

allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.

5. **19[e]. “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message”**

338. Dr. Cooklev disputes that Voith in combination with LB-031 discloses that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message. Cooklev Report at ¶ 331. Dr. Cooklev argues that “Voith does not teach that any portion of the memory 66 may be allocated to the interleaver 78 *or* the deinterleaver 90 at any one particular time depending on a message.” *Id.* I explain how Voith in combination with LB-031 discloses this limitation at paragraphs 561 through 565 of my Opening Report.

339. In arguing that claim 19 of the ’473 patent is not invalid for failing to meet the written description requirement, Dr. Cooklev states that “disclosure . . . is found generally [in the Family 3 patents] because the specification discloses the use of ‘shared memory’ by an interleaver and a deinterleaver.” Cooklev Report at ¶ 82. He argues that “[a] POSITA would understand from the disclosure of shared memory that is allocated to an interleaver would not be used at the same time by a deinterleaver but, instead, could be used at alternative times depending on the allocation in effect at the time.” Cooklev Report at ¶ 82. Thus, Dr. Cooklev contends that the mere disclosure in the Family 3 patents of shared memory used by an interleaver and a deinterleaver discloses “wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.” Accordingly, a skilled artisan would also understand from the disclosure of shared memory—i.e., “common memory used by at least two functions, where a portion of the memory can be used by either one of the functions”—in Voith that memory

“allocated to the interleaver would not also be used at the same time by a deinterleaver but, instead, could be used at alternative times depending on the allocation in effect at the time,” as in the Family 3 patents. Cooklev Report at ¶ 82.

340. Therefore, having considered Dr. Cooklev’s arguments to the contrary, it remains my opinion that Voith in combination with LB-031 discloses that “at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.”

341. Accordingly, it remains my opinion that Voith in combination with LB-031 discloses all of the limitations of claim 19 of the ’473 patent.

## **6. Motivation to Combine Voith and LB-031**

342. Dr. Cooklev disputes that a skilled artisan would have been motivated to combine the teachings of Voith with the teachings of LB-031 as recited in claim 19 of the ’473 patent. Cooklev Report at ¶ 335.

343. Dr. Cooklev argues, again without support, that “LB-031 describes a dedicated interleaver memory and a separate, dedicated deinterleaver memory where portions of a dedicated memory that is left unused by one function – because one transceiver supports more memory for a given latency path than is supported by the other transceiver with which it is communicating – is not available for use by the other function.” *Id.* at ¶ 338. I disagree. As I have explained (*see, e.g., supra*, § VII.B.1.a), a skilled artisan would have understood the disclosures of LB-031 to apply generally to VDSL2 implementations, regardless of whether they use dedicated or shared memory.

344. Dr. Cooklev also argues that Voith “does not disclose ‘sharing memory for interleaving and deinterleaving to support various applications.’” Cooklev Report at ¶ 339. He states that “Voith merely teaches that it is preferable to implement the memory buffers off-

chip,” but that Voith makes no proposal for reducing the sizes of the memory buffers. *Id.* But as I explained in my Opening Report, (*see* Jacobsen Opening Report at ¶ 568), LB-031 explains that “[t]he interleaver is a major source of complexity in VDSL2,” (LB-031 at p. 1), and Voith discloses that efficiency in the use and management of memory is desirable. *See, e.g.*, Voith, at col. 2:26-28; col. 4:30-40. LB-031 teaches that there is a trade-off between complexity, capability, and performance. LB-031 at p. 3. Thus, one of ordinary skill in the art would have been motivated to combine the teachings of Voith with the teachings of LB-031.

**G. Mazzoni in combination with G.993.1 Renders Claim 19 of the ’473 Patent Obvious.**

345. Having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that Mazzoni in combination with G.993.1 renders claim 19 of the ’473 patent obvious.

**1. Motivation to Combine Mazzoni and G.993.1**

346. Dr. Cooklev disputes that a skilled artisan would have been motivated to combine the teachings of Mazzoni with the teachings of G.993.1 as claimed in claim 19 of the ’473 patent. Cooklev Report at ¶¶ 341-52. Specifically, Dr. Cooklev argues that “the two references are so different that a person of ordinary skill in the art would be discouraged from looking to the teaching of the other reference.” *Id.* at ¶ 341. I disagree.

347. Once again, without any support whatsoever, Dr. Cooklev asserts that “G.993.1, akin to LB-031, is yet another reference that employs a dedicated interleaver memory and a dedicated deinterleaver memory.” *Id.* at ¶ 343. As I explained (*see, e.g., supra*, § VII.A.2, ¶ 17), it is my opinion that Dr. Cooklev’s assertion amounts to speculation.

348. Dr. Cooklev disputes that a skilled artisan would have recognized the limitations of Mazzoni’s table and would have recognized that conveying interleaver parameters through the initialization messages of G.993.1 would avoid the limitations of Mazzoni’s table and would

result in a more flexible solution. Cooklev Report at ¶ 346. He argues that because “Mazzoni relies on the use of a pre-populated table of I, M, I’ and M’ parameter values, where each set of values corresponds to respective one of a number of predetermined data rates,” “[t]here is not use for a message that specifies the maximum supported interleaver or deinterleaver memory size because all data rate pairs and their corresponding I, M, I’ and M’ values that need to be supported are accounted for.” *Id.* at ¶ 347. Here, as elsewhere in his report, Dr. Cooklev’s opinion is that a skilled artisan would not be motivated to modify Mazzoni or G.993.1. But, as I explained in my Opening Report (*see* Jacobsen Opening Report at ¶ 595), a skilled artisan would have recognized the benefits of modifying Mazzoni to incorporate the initialization messages of G.993.1 to obviate the need for all asymmetrical and symmetrical services to be predefined and for the transceiver to store a table indicating the values of I, M, I’ and M’ for each of the predefined bit rates.

349. Dr. Cooklev argues that “Mazzoni provides substantial flexibility already given that it allows 12 difference [sic] service configurations.” Cooklev Report at ¶ 348. I disagree. A skilled artisan would have recognized that a total of 12 pre-defined service configurations would be limiting because it would allow each transceiver to support only those 12 pre-defined services. Indeed, Mazzoni itself recognizes the limitation and discloses that it may be necessary to modify the parameters stored in the table. *See* Mazzoni at col. 5:21-30.

350. Dr. Cooklev also argues that “[a]n additional reason why G.993.1’s exchange of maximum supported memory sizes would not be recognized as beneficial to Mazzoni is that it is incompatible.” Cooklev Report at ¶ 349. Dr. Cooklev argues that “[i]f the Mazzoni VTU-O received a message indicating that the VTU-R supported a maximum downstream deinterleaver memory of 24,960 bytes and a maximum upstream interleaver memory of 10,860 bytes (based

on the maximum interleaver delay), this information would be useless to the VTU-O” because “it already has the information necessary to support the service for which both transceivers have been preconfigured at the time of installation,” and “neither the VTU-O or VTU-R would actually be capable of simultaneously supporting both maximum interleaver and deinterleaver sizes at the same time because the total memory size of the Mazzoni transceivers is only 26,890 bytes. . . .” Cooklev Report at ¶ 349. Dr. Cooklev’s hypothetical example assumes that the skilled artisan would merely add the message of LB-031 to the transceiver of Mazzoni without any modification, because his point appears to be that the memory described in Mazzoni is not large to accommodate the transmission parameters described in LB-031. This argument is specious, because it would be trivial to one of ordinary skill in the art to select a different-sized memory for the interleaver/deinterleaver pair. As I explained above and in my Opening Report (*see* Jacobsen Opening Report at ¶ 626), the skilled artisan would have recognized the inherent limitations of Mazzoni’s table, and that the teachings of LB-031 would enable the transceivers of Mazzoni to partition the shared memory between the interleaver and deinterleaver without requiring all of the possible services to be defined in advance to create the table disclosed in Mazzoni.

351. In the same vein, Dr. Cooklev argues that “per G.993.1, after the exchange of the R-MSG2 and the O-MSG2 messages, the VTU-R transmits an R-CONTRACT1 message to the VTU-O including a ‘proposed downstream contract,’” and “the VTU-O transmits the O-CINTRACT1 [sic] message to the VTU-R which contains a proposed upstream contract and a downstream contract, where the downstream contract is based on the R-CONTRACT1.” *Id.* at ¶ 350. He states that “Mazzoni already has the information necessary to support the service for which both transceivers have been preconfigured at the time of installation and does not need to

rely on messages to convey the redundant information.” *Id.* Once again, Dr. Cooklev’s hypothetical example and argument assume that the skilled artisan would merely add the messages of G.993.1 to the transceiver of Mazzoni without any modification. *See also*, Cooklev Report at ¶ 351. Dr. Cooklev’s argument appears to be that the messages of G.993.1 are superfluous when added to Mazzoni without modification. *See* Cooklev Report at ¶ 350. But as I explained above (*see supra*, § VII.A.3) and in my Opening Report (*see* Jacobsen Opening Report at ¶ 626), the skilled artisan would have recognized the inherent limitations of Mazzoni’s table, and that the teachings of G.993.1 would enable the transceivers of Mazzoni to partition the shared memory between the interleaver and deinterleaver without requiring all of the possible services to be defined in advance to create the table disclosed in Mazzoni. Consequently, the skilled artisan would have recognized that the messages of G.993.1 would allow the transceiver of Mazzoni to be modified and made more flexible. Thus, the skilled artisan would have understood that the messages of G.993.1 would not be superfluous.

352. Therefore, having considered Dr. Cooklev’s argument to the contrary, it remains my opinion that a skilled artisan would have been motivated to combine the teachings of Mazzoni with the teachings of LB-031.

2. **19[a]. “An apparatus comprising”**

353. Dr. Cooklev concedes that Mazzoni in combination with G.993.1 discloses an apparatus. Cooklev Report at ¶¶ 354-64.

3. **19[b]. “a multicarrier communications transceiver that is configured to perform an interleaving function associated with a first latency path and perform a deinterleaving function associated with a second latency path”**

354. Dr. Cooklev concedes that Mazzoni in combination with G.993.1 discloses a multicarrier communications transceiver. Cooklev Report at ¶¶ 354-64.



4. **19[c]. “the multicarrier communications transceiver being associated with a memory”**

355. Dr. Cooklev concedes that Mazzoni in combination with G.993.1 discloses that the multicarrier communications transceiver is associated with a memory. Cooklev Report at ¶¶ 354-64.

5. **19[d]. “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver”**

356. Dr. Cooklev disputes that Mazzoni in combination with G.993.1 discloses that “the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.” Cooklev Report at ¶ 354.

357. Dr. Cooklev asserts that “Dr. Jacobsen does not explain which of her arguments in [section IX.C.6.e] are applicable to [the combination of Mazzoni and G.993.1]. Cooklev Report at ¶ 355. On the contrary, the cited section states:

I have reviewed TQ Delta’s infringement contentions for this claim, and I understand TQ Delta asserts that this limitation is met by receiving the O-PMS message described in VDSL2. I do not agree that receiving the O-PMS message meets this limitation, and I do not agree with TQ Delta’s infringement read. If the Court or other trier of fact interprets the claim such that the O-PMS message meets this limitation, however, then Mazzoni in combination with G.993.1 discloses this limitation under TQ Delta’s interpretation of the claims.

I previously explained that Mazzoni discloses how the memory allocation can be determined, and reconfigured, based on the bit rate processed by a modem, above at Section IX.B.6.e, which I incorporate by reference. *See* Mazzoni, col. 1:61-65; col. 5:24-31. G.993.1 teaches sending messages during initialization that indicate maximum interleaver delay, as well as ways of allocating memory between an interleaver and a deinterleaver, as I explain above at Section IX.C.6.e, which I also incorporate by reference.

Jacobsen Opening Report at ¶¶ 585-86.

With respect to Mazzoni, section IX.B.6.e states:

Mazzoni discloses that the interleaver/deinterleaver memory has a memory allocation that “can be reconfigured in accordance with the bit rate actually processed by the send/receive device (modem).” Mazzoni, col. 1:61-65. Furthermore, Mazzoni discloses that “the sizes of the respective memory spaces assigned to the interleaving means and to the deinterleaving means” are determined “according to the bit rate of the information sent by the terminal TO (parameters I and M) and the bit rate of the information received by the terminal TO (parameters I’ and M’).” *Id.* at col. 5:24-31. One of ordinary skill in the art would have understood that this information, as well as capabilities of the transceiver at the other end of the system, would have to be conveyed, for example, in the form of a message during initialization, and that the memory would be allocated between the interleaving function and the deinterleaving function in accordance with that message.

Jacobsen Opening Report at ¶ 339.

With respect to G.993.1, section IX.C.6.e states:

As explained above, VDSL transceivers described in G.993.1 are capable of sending messages during initialization, specifying communications parameters, including interleaver and deinterleaver settings and capabilities. G.993.1 discloses transceivers that exchange initialization messages. *See* G.993.1, § 12.4.1 (“Initialization of a VTU-O/VTU-R includes a variety of tasks. The set of tasks consists of: . . . exchange of parameters (RS settings, interleaver parameters, VOC settings, bit loading and energy tables . . .”). Initialization messages include R-MSG2, sent by the VTU-R, that “transmits information about [the connection’s] bit allocation capabilities and several other features,” including the “Maximal interleaver memory,” expressed in bytes. *Id.* at § 12.4.6.3.1.1; § 12.4.6.2.1.1 (Table 12-23). Thus, G.993.1 describes a message during initialization (i.e., R-MSG2) that describes how interleaver memory can be allocated to an interleaver or a deinterleaver. It also describes how a VTU-O receives a message during initialization (i.e., R-MSG2) specifying parameters based on which the memory can be allocated (i.e., the VTU-R’s interleaver).

Similarly, G.993.1 specifies that the VTU-O transmits the message O-MSG2. *Id.* at § 12.4.6 (Figure 12-7). O-MSG2 contains the field “Maximum interleaver delay,” expressed in milliseconds. *Id.* at § 12.4.6.2.1.1 (Table 12-23). As a person

having ordinary skill in the art would have understood as of the Family 3 patents' priority date, because the interleaver delay is a function of the bit rate and interleaver depth, O-MSG2 specifies parameters that the VTU-O can use to allocate memory between an interleaver and a deinterleaver. It also discloses a transceiver, namely the VTU-R, receiving a message during initialization (i.e., O-MSG2) that the transceiver can use to allocate memory between an interleaver and a deinterleaver (i.e., the VTU-O's interleaver).

Jacobsen Opening Report at ¶¶ 447-48.

Consequently, and contrary to Dr. Cooklev's assertion, I explained, through incorporation by reference, why the combination of Mazzoni and G.993.1 discloses that the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.

358. The remainder of Dr. Cooklev's rebuttal focuses on Mazzoni and the fact that the parameters I, M, I' and M' are predefined and stored in a table. Cooklev Report at ¶¶ 356-59. I explained in my Opening Report and above that a skilled artisan would have recognized the need to define all of the services ahead of time and store all of the values of I, M, I' and M' in a table to be a disadvantage of Mazzoni because it would limit the flexibility of the implementation.

359. Dr. Cooklev repeats his argument that "G.993.1's exchange of interleaver and deinterleaver capabilities is redundant to Mazzoni's stored predefined service data rates and interleaver/deinterleaver parameters and incompatible with Mazzoni at least because the exchange of maximum supported interleaver and deinterleaver sizes per LB-031 would specify a combined amount of interleaver and deinterleaver memory that would exceed Mazzoni's total memory size." Cooklev Report at ¶ 356. I disagree. As I explained above, (*see supra*, § VII.G.1), it remains my opinion that a skilled artisan would have been motivated to combine the

teachings of G.993.1 and the teachings of Mazzoni to improve the flexibility of Mazzoni's transceiver and to obviate the need to predefine all services.

360. Therefore, having considered Dr. Cooklev's arguments to the contrary, it remains my opinion that Mazzoni in combination with G.993.1 discloses that the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.

6. **19[e]. "wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message"**

361. Dr. Cooklev disputes that Mazzoni in combination with G.993.1 discloses that "at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message." Cooklev Report at ¶ 361.

362. Dr. Cooklev's argues that "Mazzoni does not disclose exchanging any messages at all that include information about interleaving or deinterleaving parameters (or any other information upon which interleaver or deinterleaver memory allocations could be based)." Cooklev Report at ¶ 362. I disagree. As I explained in my Opening Report (*see* Jacobsen Opening Report at ¶ 344), Mazzoni discloses that the interleaver/deinterleaver memory has a memory allocation that "can be reconfigured in accordance with the bit rate actually processed by the send/receive device (modem)." Mazzoni, col. 1:61-65. Furthermore, Mazzoni discloses that "the sizes of the respective memory spaces assigned to the interleaving means and to the deinterleaving means" are determined "according to the bit rate of the information sent by the terminal TO (parameters I and M) and the bit rate of the information received by the terminal TO (parameters I' and M')." *Id.* at col. 5:24-31. As a skilled artisan would have understood, the

bit rate of the information would be determined during initialization on the basis of messages transmitted by the two transceivers.

363. Dr. Cooklev takes issue with my arguments with respect to G.993.1 in section IX.C.6.f of my Opening Report. Cooklev Report at ¶ 363. He cites only the last sentence of paragraph 452 and argues “[t]hat an interleaver and deinterleaver operate at the same time does not disclose or require that a portion of the memory be allocated to the interleaver function or deinterleaver function at any one particular time depending on the message.” *Id.* He suggests that “this was a cut and paste error.” *Id.* On the contrary, Dr. Cooklev has ignored the rest of paragraph 452 as well as paragraph 451, which state, among other things:

G.993.1 discloses that the VTU-O and VTU-R exchange interleaver capabilities and requirements during initialization. Fadavi-Ardekani states that its transceiver may incorporate VDSL. Fadavi-Ardekani at col. 4:18-21. Thus, as a skilled artisan would have recognized as of the priority date of the Family 3 patents, the transceiver of Fadavi-Ardekani implementing VDSL as per G.993.1 would transmit and receive initialization messages regarding interleaving capabilities and requirements. Thus, at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.

Additionally, G.993.1 discloses that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time. G.993.1 uses Frequency Division Duplexing (FDD). G.993.1, § 6.1. In this mode, a “full-duplex” link is established between the VTU-O and VTU-R, over which data can be transmitted simultaneously in both directions. *Id.* at §§ 12.4.1, 9.2.3.4. One of ordinary skill in the art would have understood that data would need to be interleaved and deinterleaved at the same time in this mode of transmission, which would require that a portion of the memory be allocated to an interleaving function, and a portion of the memory would be allocated to a deinterleaving function.

Jacobsen Opening Report at ¶¶ 451-52.

364. Therefore, having considered Dr. Cooklev's arguments to the contrary, it remains my opinion that Mazzoni in combination with G.993.1 discloses that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.

365. Accordingly, it remains my opinion that the combination of Mazzoni and G.993.1 renders claim 19 of the '473 patent obvious.

**H. Voith In Combination With G.993.1, or, In the Alternative, Voith In Combination with G.993.1 and Mazzoni Renders Claim 19 of the '473 Patent Obvious.**

366. Having considered Dr. Cooklev's arguments to the contrary, it remains my opinion that Voith in combination with G.993.1 or, in the alternative, Voith in combination with G.993.1 and Mazzoni renders claim 19 of the '473 patent is obvious.

**1. 19[a]. "An apparatus comprising"**

367. Dr. Cooklev concedes that Voith in combination with G.993.1 discloses an apparatus. Cooklev Report at ¶¶ 365-81.

**2. 19[b]. "a multicarrier communications transceiver that is configured to perform an interleaving function associated with a first latency path and perform a deinterleaving function associated with a second latency path"**

368. Dr. Cooklev concedes that Voith in combination with G.993.1 discloses "a multicarrier communications transceiver that is configured to perform an interleaving function associated with a first latency path and perform a deinterleaving function associated with a second latency path." Cooklev Report at ¶¶ 365-81.

3. **19[c]. “the multicarrier communications transceiver being associated with a memory”**

369. Dr. Cooklev concedes that Voith in combination with G.993.1 discloses that that multicarrier communications transceiver is associated with a memory. Cooklev Report at ¶¶ 365-81.

4. **19[d]. “wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver”**

370. Dr. Cooklev disputes that Voith in combination with G.993.1 discloses that “the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver.” Cooklev Report at ¶¶ 367-70.

371. Without any support, Dr. Cooklev asserts, yet again, that “a POSITA would understand G.993.1 to provide for dedicated downstream memories in each transceiver and separate, dedicated upstream memories in each transceiver,” which he contends was “consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems, including the LB-031 modem.” Cooklev Report at ¶ 368. I disagree. As I have explained (*see supra*, § VII.A.2), Dr. Cooklev’s assertions that prior art implementations always and only used dedicated interleaver memory and dedicated deinterleaver memory are unsupported and speculative.

372. Dr. Cooklev also contends that “nothing in the G.993.1 standard suggests ‘allocating memory between an interleaver and a deinterleaver in accordance,’ with the ‘maximum interleaver delay.’” Cooklev Report at ¶ 369. Dr. Cooklev argues that “[a] POSITA would have understood that the interleaver of a G.993.1-compliant transceiver may have used less than all of its dedicated interleaver memory based on the memory capabilities of the far-end

transceiver's deinterleaving function," but that "the transceiver would not have been capable of reallocating the unused interleaver memory to its deinterleaver." *Id.* Once again, Dr. Cooklev's conclusion relies on his unsupported and speculative assertion that prior art implementations always and only used dedicated interleaver memory and dedicated deinterleaver memory, and that the existing standards prohibited an implementation from using shared memory. As I have explained, I disagree with both of these assertions. *See supra*, §§ VII.A.1, VII.A.2.

373. As I explained in my Opening Report, Voith discloses allocating the shared external interleave/deinterleaver memory and using an arbitration procedure between the two functions to do so, and G.993.1 teaches sending messages during initialization that indicate maximum interleaver delay, as well as allocating memory between an interleaver and a deinterleaver. Jacobsen Opening Report at ¶ 611. A skilled artisan would have recognized that the allocation of the shared external memory of Voith between the interleaver and deinterleaver would be in accordance with the messages sent during initialization in G.993.1.

374. Therefore, having considered Dr. Cooklev's arguments to the contrary, it remains my opinion that Voith in combination with G.993.1 discloses that "the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver."

5. **19[e]. "wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message"**

375. Dr. Cooklev disputes that Voith in combination with G.993.1, or, in the alternative, Voith in combination with G.993.1 and LB-031, discloses that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message. Cooklev Report at ¶¶ 371-73.



376. As I explained in my Opening Report and above, Voith specifically discloses that a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time. *See supra*, § VII.F.5; Jacobsen Opening Report at ¶ 562. I also explained that G.993.1 discloses that the VTU-O and VTU-R exchange interleaver capabilities and requirements during initialization. *See supra*, § VII.G.6; Jacobsen Opening Report at ¶ 451. In addition, I explained that G.993.1 uses Frequency Division Duplexing (FDD), which a skilled artisan would have understood to mean that data would need to be interleaved and deinterleaved at the same time, which would require that a portion of the memory be allocated to an interleaving function, and a portion of the memory would be allocated to a deinterleaving function. *See supra*, § VII.G.6; Jacobsen Opening Report at ¶¶ 451-52. Consequently, the combination of Voith and G.993.1 discloses that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.

377. Yet again, Dr. Cooklev asserts, without support, that “[a] POSITA would have understood that the interleaver of a G.993.1-compliant transceiver may have used less than all of its dedicated interleaver memory based on the memory capabilities of the far-end transceiver’s deinterleaving function,” but that “the transceiver would not have been capable of reallocating the unused interleaver memory to its deinterleaver.” *Id.* at ¶ 372. As I have explained, Dr. Cooklev’s conclusion relies on his unsupported and speculative assertion that prior art implementations always and only used dedicated interleaver memory and dedicated deinterleaver memory, and that G.993.1 foreclosed the use of shared memory in an implementation. As I have explained, I disagree with both of these assertions. *See supra*, §§ VII.A.1, VII.A.2.

378. Thus, having considered Dr. Cooklev's arguments to the contrary, it remains my opinion that Voith in combination with G.993.1, or, in the alternative, Voith in combination with G.993.1 and Mazzoni, discloses that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message.

#### **6. Motivation to Combine Voith and G.993.1**

379. Dr. Cooklev disputes that a skilled artisan would have been motivated to combine the teachings of Voith with the teachings of G.993.1 in the manner claimed. Cooklev Report at ¶¶ 374-80.

380. Dr. Cooklev disputes that Voith discloses a need to allocate memory for interleaving and deinterleaving. *Id.* at ¶ 378. I disagree. Voith discloses that interleaving transmit data and deinterleaving receive data are "complex functions" for which the "ADSL transceiver 34 requires a large amount of memory, which is preferably implemented off-chip in external interleave/de-interleave memory 66." Voith at col. 4:30-35. Dr. Cooklev argues that "Voith's fundamental premise is to concede that the memory buffers are required to be large but Voith makes no proposal for reducing such a requirement." Cooklev Report at ¶ 378. Even assuming Voith does not propose a solution to reduce the memory requirement, however, as Dr. Cooklev has noted, Voith identifies the problem that memory buffers are large, which would have motivated a skilled artisan to consider ways to reduce buffer size, including by consulting other references, such as G.993.1. Furthermore, whether Voith proposes to reduce the amount of memory used for interleaving and deinterleaving is irrelevant to the point I made, which is that Voith discloses a need to allocate memory for interleaving and deinterleaving.

381. Dr. Cooklev argues that "there is no disclosure or suggestion in G.993.1 of using or partitioning shared memory." Cooklev Report at ¶ 379. As an initial matter, claim 19 of the

'473 patent does not recite "shared memory." But even if it did, Dr. Cooklev's response is to an argument I did not make. I stated that G.993.1 teaches that a portion of memory can be allocated to an interleaver or a deinterleaver depending on the message, as recited in the claim. Jacobsen Opening Report at ¶ 614; *see also id.* at § IX.C.6.f ("G.993.1 discloses that the VTU-O and VTU-R exchange interleaver capabilities and requirements during initialization. . . . Additionally, G.993.1 discloses that at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time."). Moreover, as I have explained, nothing in G.993.1 would have prevented an implementation from using shared memory to implement interleaving and deinterleaving. *See supra*, §§ VII.A.1, VII.A.2.

382. Thus, having considered Dr. Cooklev's argument to the contrary, it remains my opinion that a skilled artisan would have been motivated to combine the teachings of Voith with the teachings of G.993.1 as recited in claim 19 of the '473 patent.

## **7. Addition of Mazzoni to Voith and G.993.1**

383. In attempting to rebut my argument that the combination of Voith, G.993.1, and Mazzoni renders claim 19 of the '473 patent obvious, Dr. Cooklev argues that "Mazzoni does not disclose exchanging any messages at all that include information about interleaving or deinterleaving parameters (or any other information upon which interleaver or deinterleaver memory allocations could be based)." Cooklev Report at ¶ 381. I disagree. As I explained in my Opening Report (*see* Jacobsen Opening Report at ¶ 344), Mazzoni discloses that the interleaver/deinterleaver memory has a memory allocation that "can be reconfigured in accordance with the bit rate actually processed by the send/receive device (modem)." Mazzoni, col. 1:61-65. Furthermore, Mazzoni discloses that "the sizes of the respective memory spaces assigned to the interleaving means and to the deinterleaving means" are determined "according to the bit rate of the information sent by the terminal TO (parameters I and M) and the bit rate of

the information received by the terminal TO (parameters I' and M')." *Id.* at col. 5:24-31. As a skilled artisan would have understood, the bit rate of the information would be determined during initialization on the basis of messages transmitted by the two transceivers. *See also supra*, §§ VII.C.5.d, VII.C.5.e.

#### **8. Motivation to Combine Voith, G.993.1, and Mazzoni**

384. Dr. Cooklev disputes that a skilled artisan would have been motivated to combine the disclosures of Voith, G.993.1, and Mazzoni as recited in claim 19 of the '473 patent. Cooklev Report at ¶ 382.

385. In purporting to dispute that Voith discloses that efficiency in the use of memory is desirable, Dr. Cooklev references a portion of his discussion concerning G.993.1. Cooklev Report at ¶ 384. Nevertheless, I explained above (*see, e.g., supra*, § VII.F.4, VII.F.5) why I disagree with Dr. Cooklev.

386. Dr. Cooklev also disputes that G.993.1 discloses how memory is allocated in accordance with a message received during initialization, and that a skilled artisan would have recognized that the teachings of G.993.1 show a reliable and efficient way to enable the transceivers of Mazzoni to partition the shared memory between the interleaver and deinterleaver without requiring all of the services to be defined in advance to create the table disclosed in Mazzoni. Cooklev Report at ¶ 385. Once again, without any support, Dr. Cooklev asserts that "a POSITA would understand G.993.1 to provide for dedicated downstream memories in each transceiver and separate, dedicated upstream memories in each transceiver," which he contends was "consistent with other ADSL and G.Lite-compliant modems of that era and proposals for VDSL modems, including the LB-031 modem." Cooklev Report at ¶ 385. I disagree. As I have explained (*see supra*, §§ VII.A.1, VII.A.2), Dr. Cooklev's assertions that prior art implementations always and only used dedicated interleaver memory and dedicated

deinterleaver memory and that the standards somehow precluded the use of shared memory for interleaving and deinterleaving are unsupported and speculative.

387. Finally, Dr. Cooklev argues that “a POSITA would not look to add messages (from G.993.1 or otherwise) to the system discloses in Mazzoni, and in fact doing so would provide no useful benefit.” Cooklev Report at ¶ 386. He argues that because “Mazzoni relies on the use of a pre-populated table of I, M, I' and M' parameter values, where each set of values corresponds to respective one of a number of predetermined data rates,” “[t]here is not use for a message that specifies the maximum supported interleaver or deinterleaver memory size because all data rate pairs and their corresponding I, M, I' and M' values that need to be supported are accounted for.” *Id.* As I explained in my Opening Report (*see* Jacobsen Opening Report at ¶ 595), a skilled artisan would have recognized the benefits of modifying Mazzoni to incorporate the initialization messages of G.993.1 to obviate the need for all asymmetrical and symmetrical services to be predefined and for the transceiver to store a table indicating the values of I, M, I' and M' for each of the predefined bit rates.

388. Therefore, having considered Dr. Cooklev's argument to the contrary, it remains my opinion that a skilled artisan would have been motivated to combine the teachings of Voith with the teachings of G.993.1 and with the teachings of Mazzoni as recited in claim 19 of the '473 patent.

## **VIII. CONCLUSION**


389. In my opinion, Dr. Cooklev has failed to meaningfully rebut the arguments set forth in my Opening Report regarding the teachings of the prior art discussed in my Opening Report.

390. Having reviewed and considered Dr. Cooklev's arguments and opinions, it remains my opinion that a person having ordinary skill in the art on the priority date of the

Family 3 patents would have found claim 1 of the '048 patent, claim 5 of the '381 patent, claim 13 of the '882 patent, and claim 19 of the '473 patent to be obvious in view of (a) LB-031; (b) LB-031 in combination with Mazzoni; (c) Fadavi-Ardekani in combination with G.993.1; and (d) Fadavi-Ardekani in combination with G.992.2. It is also my opinion that a person of ordinary skill in the art would have understood all of the claim elements and limitations of claim 19 of the '473 patent to be obvious in view of (a) Voith in combination with LB-031; (b) Mazzoni in combination with G.993.1; and (c) Voith in combination with G.993.1, or in the alternative, Voith in combination with G.993.1 and Mazzoni. It also remains my opinion that that the asserted claims are invalid for indefiniteness, lack of enablement, and lack of written description.

391. I reserve the right to supplement my opinions in the future to respond to any arguments or positions that TQ Delta or its experts may raise, taking account of new information as it becomes available to me.

Date: January 18, 2019



Krista S. Jacobsen

# **EXHIBIT 13**

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Page 418

IN THE UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF DELAWARE

---oOo---

TQ DELTA, LLC,

Plaintiff,

vs.

C.A. No. 13-CV-1835-RGA

2WIRE, INC.,

Defendants.

\_\_\_\_\_/

HIGHLY CONFIDENTIAL ATTORNEYS' EYES ONLY

DEPOSITION OF KRISTA S. JACOBSEN, Ph.D.

VOLUME III, PAGES 418 - 591

SAN FRANCISCO, CALIFORNIA

WEDNESDAY, FEBRUARY 6, 2019

BY: ANDREA M. IGNACIO, CSR, RPR, CRR, CCRR, CLR ~

CSR LICENSE NO. 9830

JOB NO. 12744



# HIGHLY CONFIDENTIAL ATTORNEYS' EYES ONLY

Page 419	Page 421
<p>1 IN THE UNITED STATES DISTRICT COURT</p> <p>2 FOR THE DISTRICT OF DELAWARE</p> <p>3 ---oOo---</p> <p>4</p> <p>5 TQ DELTA, LLC,</p> <p>6 Plaintiff,</p> <p>7 vs. C.A. No. 13-CV-1835-RGA</p> <p>8 2WIRE, INC.,</p> <p>9 Defendants.</p> <p>10 _____/</p> <p>11</p> <p>12 Deposition of Krista S. Jacobsen, Ph.D.,</p> <p>13 taken on behalf of the Plaintiff, on Wednesday,</p> <p>14 February 6, 2019, at Goodwin Procter LLP,</p> <p>15 601 Marshall Street, Redwood City, California,</p> <p>16 beginning at 9:11 a.m., and ending at 3:28 p.m.,</p> <p>17 Pursuant to Notice, and before me,</p> <p>18 ANDREA M. IGNACIO, CSR, RPR, CRR, CLR ~ No. 9830.</p> <p>19</p> <p>20</p> <p>21</p> <p>22</p> <p>23</p> <p>24</p> <p>25</p>	<p>1 INDEX</p> <p>2</p> <p>3 WITNESS: Krista S. Jacobsen, Ph.D. - Volume III</p> <p>4</p> <p>5 EXAMINATION PAGE</p> <p>6 By Mr. McAndrews 424</p> <p>7</p> <p>8 EXHIBITS</p> <p>9 EXHIBIT PAGE</p> <p>10 Exhibit 23 Opening Report on Invalidity of 424</p> <p>11 Dr. Krista S. Jacobsen for</p> <p>12 Family 3 patents</p> <p>13 Exhibit 24 Reply Expert Report of Dr. Krista 465</p> <p>14 S. Jacobsen for Family 3 Patents</p> <p>15 Exhibit 25 Rebuttal Expert Report on 465</p> <p>16 Non-Infringement of Dr. Krista S.</p> <p>17 Jacobsen for Family 3 Patents</p> <p>18 Exhibit 26 U.S. Patent 5,764,649 Tong 466</p> <p>19 Exhibit 27 Fundamentals of DSL Technology 466</p> <p>20 Exhibit 28 U.S. Patent 7,269,208 Mazzoni, 480</p> <p>21 Bates 2WIRE00028340 - '353</p> <p>22 Exhibit 29 ITU-Telecommunication 501</p> <p>23 Standardization Sector - VDSL2</p> <p>24 - Constraining the Interleaver</p> <p>25 Complexity, Bates 2WIRE00030957 - '963</p>
Page 420	Page 422
<p>1 APPEARANCES:</p> <p>2</p> <p>3</p> <p>4</p> <p>5 FOR THE PLAINTIFF TQ DELTA, LLC:</p> <p>6 MCANDREWS HELD &amp; MALLOY LTD</p> <p>7 By: PETER MCANDREWS, Esq.</p> <p>8 RAJENDRA A. CHIPLUNKAR, Esq.</p> <p>9 500 West Madison Street, 34th Floor</p> <p>10 Chicago, Illinois 60661</p> <p>11 Phone: 312.775.8000</p> <p>12 pwmcandrews@mcandrews-ip.com</p> <p>13</p> <p>14</p> <p>15 FOR THE DEFENDANT 2WIRE, INC.:</p> <p>16 GOODWIN PROCTER LLP</p> <p>17 By: RACHEL WALSH, Esq.</p> <p>18 Three Montgomery Center</p> <p>19 San Francisco, California 94111</p> <p>20 Phone: 415.733.6021</p> <p>21 rwalsh@goodwinlaw.com</p> <p>22</p> <p>23 THE VIDEOGRAPHER: Keigo Painter</p> <p>24</p> <p>25</p>	<p>1 EXHIBITS (Cont.)</p> <p>2</p> <p>3 EXHIBIT PAGE</p> <p>4 Exhibit 30 ITU-T G.993.1 Series G: 550</p> <p>5 Transmission Systems and Media,</p> <p>6 Digital Systems and Networks, Very</p> <p>7 high speed digital subscriber</p> <p>8 line transceivers, Bates</p> <p>9 2WIRE00030729 - '956</p> <p>10 Exhibit 31 ITU-T G.992.2 Series G: 551</p> <p>11 Transmission Systems and Media,</p> <p>12 Digital Systems and Networks,</p> <p>13 Splitterless asymmetric digital</p> <p>14 subscriber line (ADSL)</p> <p>15 Transceivers, Bates 2WIRE00052246</p> <p>16 - '424</p> <p>17 Exhibit 32 U.S. Patent 5,751,741, Bates 551</p> <p>18 2WIRE00028366 - '378</p> <p>19 Exhibit 33 U.S. Patent 6,707,822 551</p> <p>20 Fadavi-Ardekani et al, Bates</p> <p>21 2WIRE00052176 - '184</p> <p>22</p> <p>23 ---oOo---</p> <p>24</p> <p>25</p>

# HIGHLY CONFIDENTIAL ATTORNEYS' EYES ONLY

<p style="text-align: right;">Page 423</p> <p>1 REDWOOD CITY, CALIFORNIA</p> <p>2 WEDNESDAY, FEBRUARY 6, 2019</p> <p>3 9:11 A.M.</p> <p>4</p> <p>5</p> <p>6</p> <p>7 THE VIDEOGRAPHER: Here begins the videotaped</p> <p>8 deposition of Dr. Krista Jacobsen. Tape 1,</p> <p>9 Volume III.</p> <p>10 In the matter of TQ Delta versus 2Wire. Case</p> <p>11 No. 13-CV-1835 RGK.</p> <p>12 Today's date is February 6, 2019, and the</p> <p>13 time on the video monitor is 9:11.</p> <p>14 My name is Keigo Painter, and the court</p> <p>15 reporter is Andrea Ignacio, of Thompson Court</p> <p>16 Reporters.</p> <p>17 Today's deposition is taking place at Goodwin</p> <p>18 Procter in Redwood City, California.</p> <p>19 Will counsel please introduce themselves and</p> <p>20 state whom they represent, beginning with the noticing</p> <p>21 party.</p> <p>22 MR. MCANDREWS: Peter McAndrews from</p> <p>23 McAndrews, Held &amp; Malloy, on behalf of TQ Delta.</p> <p>24 MR. CHIPLUNKAR: Rajendra Chiplunkar from</p> <p>25 McAndrews, Held &amp; Malloy, on behalf of TQ Delta.</p>	<p style="text-align: right;">Page 425</p> <p>1 A That's right.</p> <p>2 Q So you're -- you understand the process?</p> <p>3 A I do.</p> <p>4 Q You seem to be doing very well with the idea</p> <p>5 that we give oral responses; right?</p> <p>6 A Understood, yes.</p> <p>7 Q Help the court reporter out like that.</p> <p>8 Are you represented by counsel today?</p> <p>9 A Yes. I have Ms. Walsh.</p> <p>10 Q Okay. Can you tell me how you prepared for</p> <p>11 your deposition today?</p> <p>12 A I reviewed my reports. I reviewed the prior</p> <p>13 art. I met with Mr. Schuman and Ms. Walsh on Monday.</p> <p>14 Q Did you -- so you said you met with them on</p> <p>15 Monday. You've had -- you had a deposition taken for</p> <p>16 the Family 2 patents yesterday; right?</p> <p>17 A Correct.</p> <p>18 Q And today is related to Family 3.</p> <p>19 Is that your understanding?</p> <p>20 A That's my understanding.</p> <p>21 Q Okay. So let me try to separate out the</p> <p>22 Family 3 preparation.</p> <p>23 So did you have a single meeting for Family 3</p> <p>24 to prepare for the deposition?</p> <p>25 A We had one meeting that covered both Family 2</p>
<p style="text-align: right;">Page 424</p> <p>1 MS. WALSH: Rachel Walsh from Goodwin</p> <p>2 Procter, on behalf of defendant 2Wire.</p> <p>3 THE VIDEOGRAPHER: Will the court reporter</p> <p>4 please swear in the witness.</p> <p>5</p> <p>6 KRISTA JACOBSEN, Ph.D.,</p> <p>7 having been sworn as a witness</p> <p>8 by the Certified Shorthand Reporter,</p> <p>9 testified as follows:</p> <p>10</p> <p>11 THE VIDEOGRAPHER: You may proceed.</p> <p>12</p> <p>13 (Document marked Exhibit 22</p> <p>14 for identification.)</p> <p>15</p> <p>16 EXAMINATION</p> <p>17 BY MR. MCANDREWS:</p> <p>18 Q Good morning, Dr. Jacobsen.</p> <p>19 A Good morning.</p> <p>20 Q Please state your full name for the record.</p> <p>21 A Krista Susan Jacobsen.</p> <p>22 Q And your current home address?</p> <p>23 A 114 George Court, Campbell, California 95008.</p> <p>24 Q Okay. You have had your deposition taken in</p> <p>25 this case twice now; right?</p>	<p style="text-align: right;">Page 426</p> <p>1 and Family 3.</p> <p>2 Q And that all occurred on Monday?</p> <p>3 A That's right.</p> <p>4 Q And how long was the meeting?</p> <p>5 A We started at 9:30, took an hour-ish for</p> <p>6 lunch, and then I think we finished around 4:00.</p> <p>7 Q Okay. Did anyone else participate in that</p> <p>8 meeting?</p> <p>9 A No.</p> <p>10 Q Any -- so no one else in person; right?</p> <p>11 A No one else in person.</p> <p>12 Q Anyone else on the phone?</p> <p>13 A No.</p> <p>14 Q Okay. Did you do any additional preparation</p> <p>15 yesterday after the Family 2 deposition ended?</p> <p>16 A I reviewed documents myself.</p> <p>17 Q Did you meet with counsel about the subject</p> <p>18 matter of the Family 3 deposition?</p> <p>19 A No.</p> <p>20 Q Did you speak to anyone on the phone about</p> <p>21 Family 3?</p> <p>22 A No.</p> <p>23 Q What documents did you review last night?</p> <p>24 A I looked at the prior art, and I looked at my</p> <p>25 own report -- reports, and I think I looked at the</p>

3 (Pages 423 to 426)

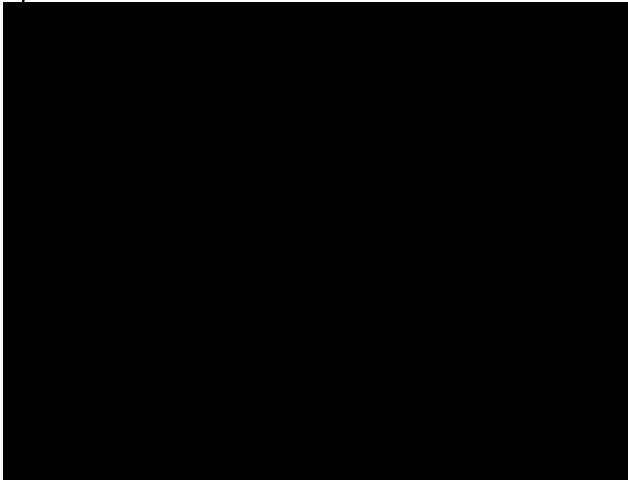
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<p style="text-align: right;">Page 427</p> <p>1 <b>VDSL2 standard.</b></p> <p>2 Q Okay. Now, let me go back a little bit</p> <p>3 further.</p> <p>4 So in preparing your expert reports for</p> <p>5 Family 3, did you consult with anybody?</p> <p>6 A <b>Not other than counsel.</b></p> <p>7 Q So for Family 3, you did not speak to Mr. Ben</p> <p>8 Miller from 2Wire?</p> <p>9 A <b>For Family 3, I don't think so.</b></p> <p>10 Q Okay. Did you speak with any other -- anyone</p> <p>11 else at 2Wire?</p> <p>12 A <b>No.</b></p> <p>13 Q Okay. So you spoke only with counsel in</p> <p>14 preparing your Family 3 reports?</p> <p>15 A <b>Yes.</b></p> <p>16 Q And was that counsel from Goodwin Procter?</p> <p>17 A <b>Yes.</b></p> <p>18 Q Was it anyone other than Ms. Walsh and</p> <p>19 Mr. Schuman?</p> <p>20 A <b>Yes. Mr. Cooper.</b></p> <p>21 Q What's Mr. Cooper's name?</p> <p>22 A <b>Monte.</b></p> <p>23 Q Full name?</p> <p>24 A <b>Monte Cooper.</b></p> <p>25 Q Okay. Did you meet with anyone in person</p>	<p style="text-align: right;">Page 429</p> <p>1 during the course of the preparation of any of your</p> <p>2 reports?</p> <p>3 A <b>No.</b></p> <p>4 Q Have you conferred with any other experts in</p> <p>5 the field of chip design?</p> <p>6 A <b>No.</b></p> <p>7 Q And -- and we're going to take a look at your</p> <p>8 reports here in a minute so you can refresh your</p> <p>9 memory.</p> <p>10 But just generally, do you know if there are</p> <p>11 any materials, that you considered in preparing your</p> <p>12 reports, that are not listed in your reports?</p> <p>13 A <b>I don't think so. I -- there's a long list</b></p> <p>14 <b>of materials at the back of my opening report, I</b></p> <p>15 <b>believe, where I -- I believe I listed everything I've</b></p> <p>16 <b>considered throughout the course of this entire case</b></p> <p>17 <b>in -- in assessing all of the families. And I believe</b></p> <p>18 <b>that list is comprehensive.</b></p> <p>19 Q Okay. Just for a little bit of baseline</p> <p>20 terminology, I've -- I've referenced Family 3.</p> <p>21 When I say "the Family 3 patents," do you</p> <p>22 understand that, for purposes of this case, to include</p> <p>23 U.S. Patent No. 7,836,381, Patent No. 7,844,882,</p> <p>24 Patent No. 8,276,048, and Patent No. 8,495,473?</p> <p>25 A <b>Yes.</b></p>
<p style="text-align: right;">Page 428</p> <p>1 during the preparation of your Family 3 reports?</p> <p>2 A <b>I don't think so. I think it was all on the</b></p> <p>3 <b>phone.</b></p> <p>4 Q Did you speak with -- so beyond Goodwin</p> <p>5 Procter counsel and -- did you speak with anyone else</p> <p>6 about your Family 3 reports, or the subject matter of</p> <p>7 the reports?</p> <p>8 A <b>I spoke with Mr. Eichmann at one point.</b></p> <p>9 Q And this is the conversation that we</p> <p>10 discussed briefly yesterday, where you had a</p> <p>11 discussion with Mr. Eichmann about the prior art --</p> <p>12 I'm sorry -- about the prosecution history of the</p> <p>13 Family 3 patents?</p> <p>14 A <b>That's right.</b></p> <p>15 Q Do you recall when that occurred?</p> <p>16 A <b>I don't -- I don't remember. Last year at</b></p> <p>17 <b>some point, but I -- I don't know if it was November</b></p> <p>18 <b>or December.</b></p> <p>19 Q Okay. Did you provide -- as you've done with</p> <p>20 the prior families, Family 1 and Family 2, did you</p> <p>21 provide to Mr. Eichmann any kind of ranking of the</p> <p>22 Family 3 patents?</p> <p>23 A <b>I don't believe so. I don't believe I was</b></p> <p>24 <b>asked to do that.</b></p> <p>25 Q Okay. Did you confer with anyone at Broadcom</p>	<p style="text-align: right;">Page 430</p> <p>1 Q And if I refer to an individual patent by its</p> <p>2 last three numbers, you would understand that I'm</p> <p>3 referring to one of those four patents?</p> <p>4 A <b>Yes, I would.</b></p> <p>5 Q Okay. And let me do this one now.</p> <p>6 So you understand that there's a number of</p> <p>7 2Wire products at issue in the case?</p> <p>8 A <b>I do.</b></p> <p>9 Q And do you understand that those products for</p> <p>10 Family 3, that have been accused of infringement and</p> <p>11 are still at issue currently, are the 2Wire model Nos.</p> <p>12 5031NV?</p> <p>13 Do you understand that one is involved?</p> <p>14 A <b>I do.</b></p> <div style="background-color: black; width: 100%; height: 150px; margin-top: 10px;"></div>

4 (Pages 427 to 430)

# HIGHLY CONFIDENTIAL ATTORNEYS' EYES ONLY

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17 Q And if you have any distinction you'd like to  
18 make amongst those, please let me know. I'll try to  
19 separate them out, where I have an idea that there may  
20 be some distinction, but please do that.  
21 A I will. Thank you.  
22 Q Okay. So just as we -- we've -- we spent  
23 some time on your background in some earlier  
24 depositions, so I'm not going to rehash that.  
25 But a little more specifically, I'd like to

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1 understand your background in designing any aspects of  
2 an interleaver or de-interleaver.  
3 Can you tell me, do you have any experience  
4 in that area?  
5 A I have not personally designed an interleaver  
6 or de-interleaver. It is the type of functionality  
7 that systems engineers know and understand. So I have  
8 that system level understanding of it.  
9 Q So you have a -- you have a -- so what you're  
10 saying is, you have a -- you have a functionality  
11 understanding, in the sense that you understand the  
12 way in which an interleaver can manipulate bytes or --  
13 I guess more generically, I've seen in your books  
14 referred to as symbols?  
15 A Correct.  
16 Q Today, if we refer to them as -- so isn't it  
17 generally true that, in the DSL art, it's manipulating  
18 the order or spacing of -- of bytes?  
19 A Yes --  
20 Q Okay.  
21 A -- in the DSL space.  
22 Q Okay. So I think, in some of these  
23 references, more generically, sometimes that's  
24 referred to symbol as the unit that is being shuffled  
25 or spread out. But today, I'm generally going to be

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1 referring to those as -- as bytes.  
2 If there's a distinction you want to make  
3 when we're looking at a particular reference, please  
4 call that out.  
5 A Okay.  
6 Q Okay. So from a functionality level, you  
7 understand the inputs and the outputs of the  
8 interleaver operation; is that right?  
9 A Yes.  
10 Q And you understand the algorithms by which  
11 bytes can be spread; correct?  
12 A Yes, yes.  
13 Q Okay. So -- but when you said that you had  
14 not been involved in designing an interleaver or  
15 de-interleaver, are you -- are you referring more  
16 to -- so first of all, the -- the physical hardware  
17 that's used for that?  
18 A Right.  
19 There are different ways to implement an  
20 interleaver or de-interleaver, hardware or software.  
21 I'm not a chip designer, so I have not designed  
22 hardware to perform interleaving or de-interleaving.  
23 Q And have you specifically written any  
24 algorithm that will cause interleaving or  
25 de-interleaving to occur?

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1 A Possibly in the context of simulations of  
2 our -- of systems. I don't remember offhand.  
3 Q Do you remember what type of interleaver you  
4 were simulating, if you -- if that's actually what you  
5 did?  
6 A I don't remember. Given that the context  
7 would have been DSL, it likely would have been a  
8 convolutional interleaver.  
9 Q Okay. So -- so to the extent that you have  
10 had any experience simulating an interleaver, you  
11 would have been simulating a convolutional  
12 interleaver?  
13 A Most likely.  
14 Q Okay. And that's because generally, the --  
15 the interleaver operation for DSL is convolutional  
16 interleaving?  
17 A Typically, yes.  
18 Q Okay. You're -- you're aware that in -- so  
19 is it true that, in the DSL standards that are -- or  
20 the DSL standard, I guess, that is relevant to the  
21 infringement side of the case, at least, VDSL2, that  
22 VDSL2 only uses convolutional interleaving?  
23 A That's right.  
24 Q Okay. And is it also true that -- so we're  
25 going to be referencing some prior art today. And to

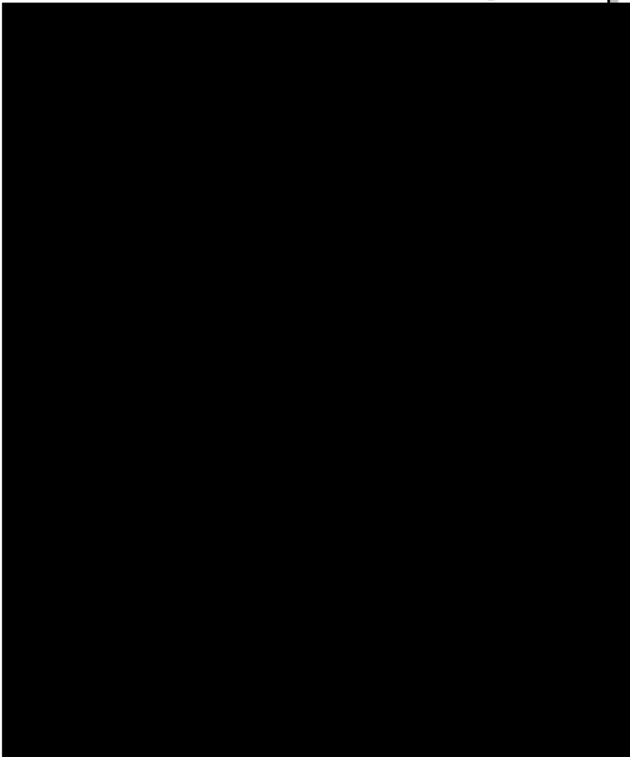
5 (Pages 431 to 434)

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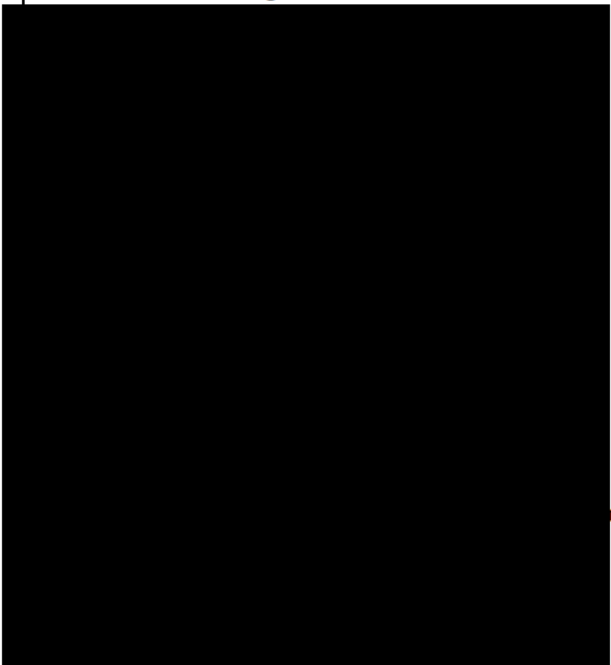
1 the extent that that prior art is intended to be for  
2 ADSL or ADSL2, that would also be only convolutional  
3 interleaving?  
4 A That's correct.  
5 Q Okay. And there may be -- I -- I can't  
6 recall right now. There may be some prior art  
7 references that are in the context of T1.413, which is  
8 a predecessor to the ITU DSL standards; is that right?  
9 A That's right.  
10 Q Okay. And T1.413 Issue 1 and Issue 2 both  
11 only use convolutional interleaving; is that right?  
12 A That's correct.  
13 Q Okay. So when you -- to the extent -- and I  
14 know that you're trying to remember if you actually  
15 did this.  
16 But did your simulation work involve  
17 determining how much memory or the layout of any  
18 memory that would be required to implement what you  
19 were simulating?  
20 A I don't remember. I don't think so, but I  
21 don't remember.  
22 Q Okay. So you have worked in the past with at  
23 least one company, maybe overlapping. So -- so you  
24 worked with TI; right?  
25 A Correct.

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1 Q And TI was in the business of designing and  
2 producing DSL chipsets; correct?  
3 A That's right.



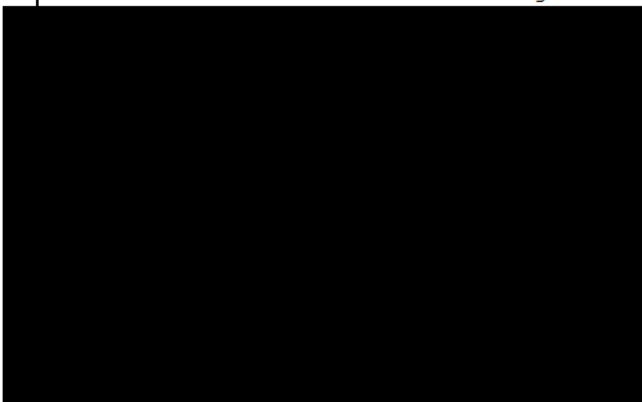
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6 (Pages 435 to 438)

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14 So what time frame -- during what time frame  
15 did you participate in ITU-related DSL standards  
16 development?

17 A ITU specifically?

18 Q Correct.

19 A Starting in early 2000 -- I believe it was  
20 early 2000 -- and through the summer of 2006.

21 Q Okay. And then, before 2000, did you also  
22 participate in the T1.413 DSL-related standards  
23 bodies?

24 A I did. T1/E1.4, and also ETSI TM6.

25 Q And the -- the DSL-related standards that

Page 440

1 resulted from the T1/E1.4 work were the two T1.413  
2 standards?

3 A One of them -- I was not involved in Issue 1.  
4 That was complete before I began working in T1/E1.4.  
5 So it would have been T1.413 Issue 2. And then there  
6 were other assorted DSL-related standards, such as  
7 spectrum management. I think it was T1.417. There  
8 was a VDSL standard being developed, and I was working  
9 on that as well.

10 Q Did that ever result in an approved standard,  
11 the VDSL work for T1/E1?

12 A They published -- oh, man -- they published  
13 something, and I don't remember if it was just a  
14 system requirements document, or if it had more of the  
15 details of the transceiver itself. I can't remember.

16 Q So during your time with T1/E1 and with the  
17 ITU DSL-related standards development, did you  
18 personally contribute any concepts for interleaving or  
19 de-interleaving?

20 A Not other than what potential values of  
21 interleave depth and FEC code word size, that -- that  
22 level.

23 Q Can you be more specific to that?

24 Was there something about -- what particular  
25 aspect of that?

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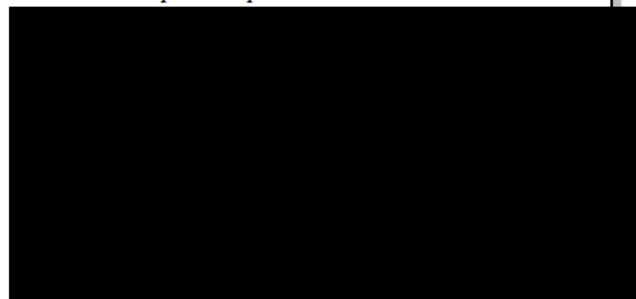
1 A Talking about, for example, impulse noise  
2 immunity, and how to best create a system that would  
3 be able to withstand particular durations of impulse  
4 noise.

5 And as you know, the interleaver spreads the  
6 code word out over time, and its impulse noise  
7 immunity is dependent on how much spread out it is.

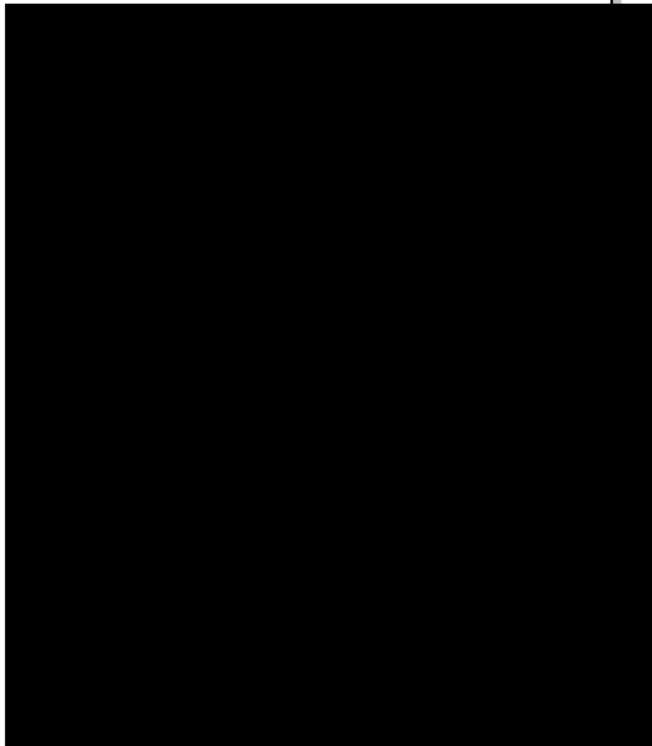
8 Q And so, are you talking about something as  
9 simple as, We need an interleaver depth of X?

10 Or was it something maybe a little bit more  
11 specific, like, We want -- we want a code word size of  
12 X with Y number of parity bytes?

13 We want an interleaver block size of Y, and  
14 we want a depth of Z, and that's going to optimize  
15 some aspect of impulse noise?



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7 (Pages 439 to 442)

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8 (Pages 443 to 446)



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3 So -- so if a document was -- was called  
4 "993.1 Foundation" or "Foundations," what would --  
5 what would that mean to you?

6 A That is my understanding of the  
7 characterization of the first VDSL document published  
8 by the ITU.

9 Q Okay. And -- and you would characterize that  
10 as essentially a draft 993.1 standard?

11 A I would characterize it as a -- an early  
12 version, potentially not a complete standard,  
13 specifying everything that would normally be specified  
14 in a full standard.

15 Q Are you familiar with anyone having attempted  
16 to commercialize a product based on that Foundations  
17 document?

18 A I'm not aware of anyone.

9 (Pages 447 to 450)



HIGHLY CONFIDENTIAL  
ATTORNEYS' EYES ONLY

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10 (Pages 451 to 454)

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11 (Pages 455 to 458)

# HIGHLY CONFIDENTIAL ATTORNEYS' EYES ONLY

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10 Q Okay. And so your discussion of, for  
11 example, Tong's implementation, was simply to  
12 illustrate that there may be additional amounts of  
13 memory -- there may be -- theoretically, there may be  
14 additional amounts of memory beyond  
15 I minus 1/D minus 1 over 2 that are used; correct?  
16 A Well, that discussion, I believe, proves  
17 conclusively that there -- that there is always more  
18 than I minus 1 times D minus 1 over 2, because you  
19 have to somewhere save the -- the addresses -- the  
20 read and write addresses.  
21 So the amount of memory used is always a  
22 little bit more than that, even in a very efficient  
23 implementation.  
24 Q So let's talk about that.  
25 So the -- the memory addresses that you're

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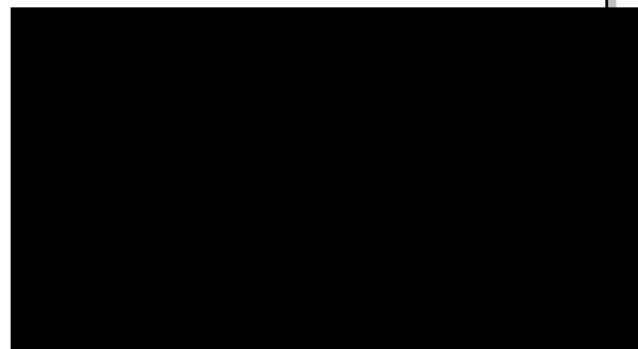
1 pointers that are stored, and each require a byte of  
2 memory to store the pointers; right?  
3 A At least a byte, yes.  
4 Q Okay. And I think, in Tong's implementation,  
5 they're a single byte, but we can look at that. You  
6 can correct that.  
7 So let's, just for argument's sake, say that  
8 there are three bytes with three pointers stored;  
9 right?  
10 A Okay.  
11 Q Okay. And do you have an understanding of  
12 how many versions of those three pointers would have  
13 to be stored in the memory?  
14 A I would have to look at it.  
15 Q Okay. So we can go there, but let me -- let  
16 me cover something that -- so we can go over what is  
17 the amount.  
18 So what I'm going to try to get to is, what  
19 is the amount that's necessary to store those?  
20 And we can do that when we look at the  
21 specific details. But I want to ask a more general  
22 question.  
23 Is it your position that those memory  
24 pointers necessarily must be stored in the  
25 interleave/de-interleave memory?

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1 talking about, you're talking about in -- in Tong's  
2 implementation, he stores what -- and you can tell me  
3 if I'm wrong about this, but Tong's implementation  
4 will store essentially three parameters times the  
5 block length; correct?  
6 A I'm not sure what you mean by "times the  
7 block length."  
8 Q So there are -- there are three parameters,  
9 and you're talking about three memory addresses;  
10 right?  
11 A Right.  
12 Q And when I say "memory addresses," let's --  
13 let me be a little more specific.  
14 So there will be three memory locations that  
15 will store something; right?  
16 A I would have to review it. I mean, off the  
17 top of my head, I don't remember that.  
18 Q Okay. We can pull that out.  
19 But I'm -- so -- so is it -- and we can go to  
20 the document if -- but I -- I'm feeling you're going  
21 to have an understanding at this level, so let me just  
22 try it.  
23 So those -- those are memory pointers?  
24 A That's right.  
25 Q Okay. So -- so there are three memory

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1 A It's not necessary that they're stored there,  
2 but they need to be stored somewhere.  
3 Q Okay. So if -- if you've got a -- a block of  
4 shared interleaver/de-interleaver memory, and the  
5 design detail was that those memory addresses are not  
6 stored there, then those -- those memory pointers  
7 would not be using any portion of the  
8 interleaver/de-interleaver memory; right?  
9 A It would depend on the implementation.  
10 Q Right.  
11 So -- so the answer is, it's true that those  
12 are not necessarily stored in the  
13 interleaver/de-interleaver memory?



12 (Pages 459 to 462)

# HIGHLY CONFIDENTIAL ATTORNEYS' EYES ONLY

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1 correct?

2 **A That's right. They're addresses.**

3 Q And -- and so they don't store information

4 that is being de-interleaved; correct?

5 **A Correct.**

6 MR. MCANDREWS: Okay. Take a short break.

7 THE VIDEOGRAPHER: Going off the record. The

8 time is now 10:10.

9 (Recess taken.)

10 THE VIDEOGRAPHER: Going on the record. The

11 time is now 10:26.

12 (Documents marked Exhibits 23 - 25

13 for identification.)

14 MR. MCANDREWS: Okay.

15 Q I'm going to hand you -- I should have done

16 this earlier. But let me hand you three exhibits that

17 have been marked Exhibit 23, 24, and 25.

18 Exhibit 23 is entitled:

19 "Opening Expert Report on Invalidity of

20 Dr. Krista S. Jacobsen for Family 3 Patents."

21 Exhibit 24 is:

22 "Reply Expert Report of Dr. Krista S.

23 Jacobsen for Family 3 Patents."

24 And 25 is:

25 "Rebuttal Expert Report on Non-infringement

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3 MR. MCANDREWS: Q. So according to Tong --

4 and -- and I'll get it out in a minute. I'm not

5 trying to -- it's not a memory test.

6 But other than storing memory pointers, is

7 there -- are there -- is there any other use of memory

8 that's necessary, beyond I minus 1 times D minus 1

9 over 2?

10 **A I'm not sure. I would have to look at it.**

11 Q Okay. So one more question, and I think

12 we'll take a short break.

13 But the -- the question is, those -- those

14 memory pointers that are stored in -- so let's call

15 it -- there's -- there's at least three bytes of

16 memory that store memory pointers in Tong's

17 implementation.

18 Those memory pointers are not Reed-Solomon

19 encoded data bytes; correct?

20 **A That's right.**

21 Q So those memory locations are not being used

22 to store Reed-Solomon coded data bytes?

23 **A That's correct.**

24 Q Those are not -- those memory locations do

25 not store information that is being interleaved;

1 of Dr. Krista S. Jacobsen for Family 3 Patents."

2 I'll hand those to you.

3 **A Thank you.**

4 Q Dr. Jacobsen, if you could look at those

5 briefly, and just confirm that those are the

6 three expert reports that you have submitted related

7 to Family 3 in this litigation.

8 **A They do appear to be that.**

9 Q Okay. I'm not actually going to have you

10 refer to any of them right now, but they're there in

11 front of you if you want to reference anything to help

12 you answer a question.

13 (Documents marked Exhibits 26 - 27

14 for identification.)

15 MR. MCANDREWS: I'm additionally going to

16 hand you right now what's been marked as Exhibit 26.

17 It's U.S. Patent No. 5,764,649, naming Po Tong as the

18 sole inventor.

19 And Exhibit 27, which are -- which includes

20 excerpts from a book entitled:

21 "Fundamentals of DSL Technology."

22 Edited by Philip Golden, Hervé Dedieu, and

23 Krista S. Jacobsen.

24 Q So Exhibit 20 -- let's actually start with

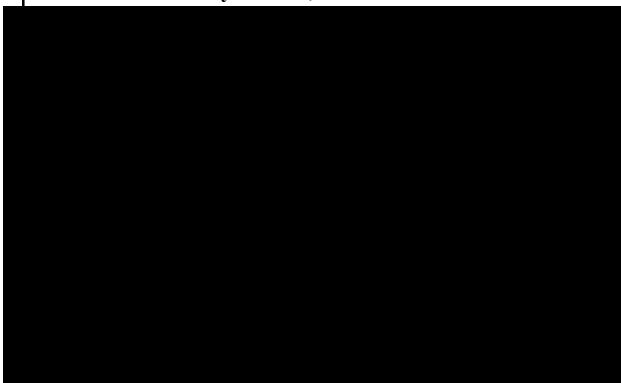
25 Exhibit 27.

13 (Pages 463 to 466)

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1       **A (Witness complies.)**  
 2       Q So can you tell me what Exhibit 27 is?  
 3       **A Exhibit 27 appears to be Chapter 9 from the**  
 4       **book that I edited.**  
 5       Q Okay. And who authored Chapter 9?  
 6       **A Cory Modlin, M-O-D-L-I-N.**



20       Q Okay. So if you could turn to -- and this  
 21       is, again, an excerpt. But if you could turn to  
 22       page 262.  
 23       **A (Witness complies.)**  
 24       Q And I actually think the section begins on  
 25       261 in Section 9.4.1, entitled:

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1       "Optimum Memory Implementation Using Tong's  
 2       Method."  
 3       Do you see that?  
 4       **A I do.**  
 5       Q Do you recall that you referenced this  
 6       section of this book in your rebuttal expert report?  
 7       **A I recall referencing it because Dr. Cooklev**  
 8       **had referenced it.**  
 9       Q Okay. And you were pointing out that an  
 10       example of an interleaver, that uses more memory than  
 11       I minus 1 times D minus 1 over 2 is Tong's  
 12       interleaver; is that right?  
 13       **A I don't think that's an accurate**  
 14       **characterization.**  
 15       Q Okay. If you want to -- maybe we can find  
 16       where you referenced Tong.  
 17       **A (Witness complies.)**  
 18       Q Did you find where you referenced Tong?  
 19       **A I did.**  
 20       Q Okay. Can you explain to me how you relied  
 21       on Tong?  
 22       **A Well, in -- I found one place. I should say**  
 23       **I don't know that this is the only place.**  
 24       **But Dr. Cooklev had --**  
 25       Q I'm sorry. And where is that?

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1       It's in Exhibit 25?  
 2       **A It's Exhibit 25, starting around**  
 3       **paragraph 29.**  
 4       **And I was responding to Dr. Cooklev's**  
 5       **arguments and his reference of this portion of the**  
 6       **book.**  
 7       Q Okay.  
 8       **A And in paragraph 30, I was pointing out that**  
 9       **Dr. Modlin, in this chapter, had made clear that the**  
 10       **amount of memory, even in a near optimal**  
 11       **implementation, is more than Dr. Cooklev suggests was**  
 12       **actually used.**  
 13       Q Okay. And so, now that we've got it in front  
 14       of us, the way in which it is more -- and I think if  
 15       we can refer to -- I guess it's the last paragraph in  
 16       that section. But feel free to refer me elsewhere in  
 17       the section. But the last paragraph in Section 9.4.1  
 18       says:  
 19       "The de-interleaver can work exactly the same  
 20       way. With the de-interleaver, the delays are  
 21       I minus 1/D minus 1, plus 1, I minus 2/D minus 1,  
 22       plus 1, and so on.  
 23       "The memory required for either the  
 24       interleaver or de-interleaver is I minus 1 times  
 25       D minus 1 over 2, plus 1, plus the memory required to

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1       store A, L, and U, which is typically much smaller  
 2       than the interleaver or de-interleaver memory itself."  
 3       Do you see that?  
 4       **A Yes.**  
 5       Q Okay. So Tong's implementation uses  
 6       I minus 1 times D minus 1 over 2, plus 1, plus the  
 7       memory required to store A, L, and U. So let's --  
 8       let's break that down.  
 9       So the first part of it, I minus 1/D minus 1  
 10       over 2, that's what you would describe as the minimum  
 11       amount of memory necessary to implement an interleaver  
 12       or de-interleaver, given a particular I and D value;  
 13       correct?  
 14       **A A convolutional interleaver.**  
 15       Q A convolutional interleaver using a  
 16       triangular configuration?  
 17       **A That would be one way to do it.**  
 18       Q Okay. So since we've already spoken about  
 19       what I believe is the A, L, and U, are the A, L, and  
 20       U -- can you confirm that those are the memory  
 21       pointers we were discussing earlier?  
 22       **A Yes.**  
 23       Q Okay. And I had -- I had asked you this  
 24       question. I don't know that you had an opinion on it.  
 25       But my question was: How many versions of A,

14 (Pages 467 to 470)

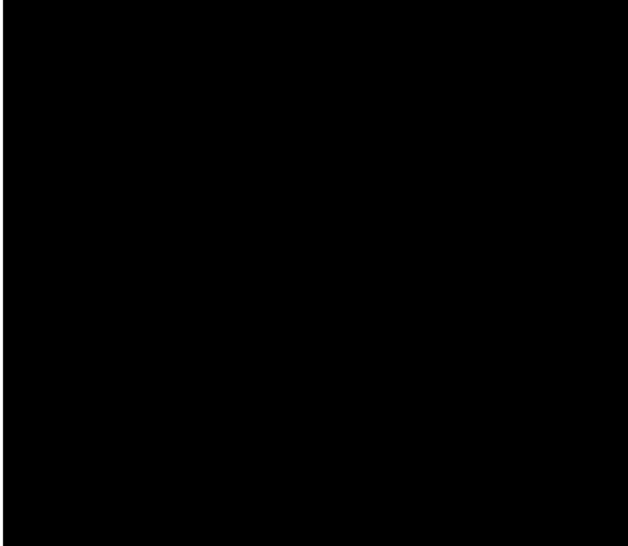
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<p style="text-align: right;">Page 471</p> <p>1 L, and U are necessary to store?</p> <p>2 <b>A Well, each of them is length I. So it would</b></p> <p>3 <b>be A times I, plus L times I, plus U times I.</b></p> <p>4 Q You're reading the sentence that says:</p> <p>5 "In Tong's method, three arrays of length I</p> <p>6 are stored, A, L, and U, with the current address, the</p> <p>7 lower limit on the address, and the upper limit on the</p> <p>8 address, respectively."</p> <p>9 <b>A That's right.</b></p> <p>10 Q Okay. And so that sentence tells us, first</p> <p>11 of all, that A is storing the pointer for the current</p> <p>12 address, L is storing the pointer for the limit on --</p> <p>13 the lower limit on the address, and U is storing the</p> <p>14 pointer for the upper limit on the address?</p> <p>15 <b>A That's how I read it.</b></p> <p>16 Q Okay. And what is your understanding about</p> <p>17 the length of those pointers --</p> <p>18 <b>A Well --</b></p> <p>19 Q -- in terms of bits?</p> <p>20 <b>A It says that three arrays of length I are</b></p> <p>21 <b>stored. And I -- just verifying whether he has I</b></p> <p>22 <b>in -- I is in symbols. So it would be I times A</b></p> <p>23 <b>symbols, L times I symbols, and U times I symbols.</b></p> <p>24 Q So -- so does that mean that whatever A is is</p> <p>25 stored I number of times?</p>	<p style="text-align: right;">Page 473</p> <p>1 I pointed to at the -- the last sentence of this</p> <p>2 section, it says:</p> <p>3 "The memory required to store A, L, and U,</p> <p>4 which is typically much smaller than the interleaver</p> <p>5 or de-interleaver memory itself."</p> <p>6 Do you see that?</p> <p>7 <b>A I do.</b></p> <p>8 Q Do you understand that sentence to be</p> <p>9 distinguishing the memory required to store the A, L,</p> <p>10 and U from the interleaver and de-interleaver memory</p> <p>11 itself?</p> <p>12 <b>A I understand it to be distinguishing between</b></p> <p>13 <b>the memory that's used to manipulate the bytes</b></p> <p>14 <b>themselves as distinct from the memory potentially</b></p> <p>15 <b>where the pointers are -- are stored.</b></p> <p>16 Q Okay. And at least Mr. Modlin is referring</p> <p>17 to -- the memory used to store the Reed-Solomon</p> <p>18 encoded data bytes that will be manipulated, he's</p> <p>19 referring that to the interleaver/de-interleaver</p> <p>20 memory itself; right?</p> <p>21 <b>A Well, he -- I think he's referring to memory</b></p> <p>22 <b>overall. He says the memory required for the</b></p> <p>23 <b>interleaver or de-interleaver is this amount plus this</b></p> <p>24 <b>amount.</b></p> <p>25 Q Yes. So -- right, so the memory required.</p>
<p style="text-align: right;">Page 472</p> <p>1 I'm trying to understand what you mean by I</p> <p>2 multiplied by A. I mean, A is an address; right?</p> <p>3 <b>A Right.</b></p> <p>4 <b>But it says in the sentence that you read:</b></p> <p>5 <b>"In Tong's method, three arrays of length I</b></p> <p>6 <b>are stored."</b></p> <p>7 Q Is it possible what that means is that there</p> <p>8 is -- there is an A, an L, and a U, and each A, each</p> <p>9 L, each U is stored I number of times?</p> <p>10 In other words, there is a -- there are</p> <p>11 three memory pointers for each line in the</p> <p>12 interleaver, effectively, each -- each I of -- of the</p> <p>13 interleaver?</p> <p>14 <b>A I think that's what I -- I'm saying.</b></p> <p>15 Q Okay.</p> <p>16 <b>A Yes.</b></p> <p>17 Q I'm sorry. Okay.</p> <p>18 <b>A I -- I think we agree on that.</b></p> <p>19 Q Okay. So -- so assuming that A is one byte</p> <p>20 and L is one byte and U is one byte, then there --</p> <p>21 then there would be 3 times I additional bytes of</p> <p>22 memory used to store those memory pointers?</p> <p>23 <b>A That's how I read it.</b></p> <p>24 Q Okay. I'll come back to that.</p> <p>25 Then -- and you see in the -- so the sentence</p>	<p style="text-align: right;">Page 474</p> <p>1 But then he goes -- would you agree with me</p> <p>2 that he's attempting to distinguish -- in the last</p> <p>3 part of the sentence, he's trying to contrast memory</p> <p>4 required to store A, L, and U from interleaver or</p> <p>5 de-interleaver memory itself?</p> <p>6 <b>A I see that he does that.</b></p> <p>7 Q Okay. And you would understand the</p> <p>8 interleaver and de-interleaver memory itself to mean</p> <p>9 the memory being used to store the Reed-Solomon</p> <p>10 encoded data bytes; correct?</p> <p>11 <b>A I would understand that, from here to be the</b></p> <p>12 <b>amount of memory I minus 1 times D minus 1 over 2,</b></p> <p>13 <b>plus 1.</b></p> <p>14 Q Okay. Okay.</p> <p>15 Now, the plus -- let's talk about the plus 1.</p> <p>16 I -- I don't think you discuss the plus 1 in your</p> <p>17 report.</p> <p>18 But is it true that the plus 1 is there</p> <p>19 because Tong's interleaver actually implements one</p> <p>20 additional byte of delay?</p> <p>21 I'm sorry. Let me strike that.</p> <p>22 Isn't it true that the plus 1 is there</p> <p>23 because Tong's interleaver actually implements</p> <p>24 two additional bytes of end-to-end delay?</p> <p>25 <b>A Well, it -- it -- the way that Cory has</b></p>


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1 explained it is that:  
2 "By reading and then writing the same memory  
3 location each cycle, there is a fixed delay of one  
4 additional symbol in the interleaver and one  
5 additional symbol in the de-interleaver."  
6 So that, as you said, the total delay is  
7 I minus 1 times D minus 1, plus 2, end-to-end.



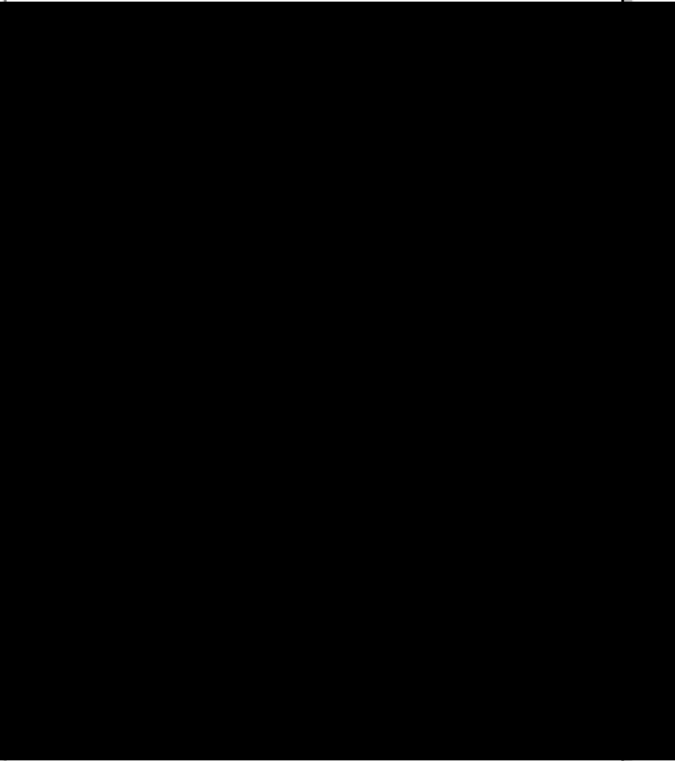
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16 (Pages 475 to 478)

# HIGHLY CONFIDENTIAL ATTORNEYS' EYES ONLY

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1 inventors participating in any standards body that you  
2 were involved in?

3 **A I don't recall.**

4 Q Do you recall whether STMicroelectronics  
5 participated in any of the DSL standards bodies you  
6 were involved in?

7 **A Yes, they did.**

8 Q Okay. Do you recall -- well, when did you  
9 first become aware of the Mazzoni reference?

10 **A During the course of this -- this litigation.**

11 Q Okay. So earlier, we had a discussion about  
12 kind of the -- the use of the term VDSL and -- and how  
13 the -- how the VDSL standards evolved over time.

14 Do you recall that?

15 **A Yes.**

16 Q Okay. You're a patent attorney; correct?

17 **A Yes.**

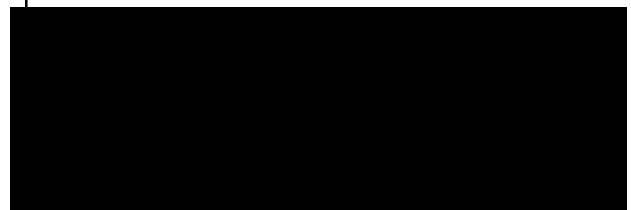
18 Q So you know how to read the front page of a  
19 document or a patent with its -- essentially, its  
20 bibliographic information?

21 **A I do.**

22 Q And can you tell me, what is the priority  
23 date of the Mazzoni reference?

24 **A Well, based on the -- when you say "priority  
25 date," which -- in the U.S.?**

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8 for identification.)  
9 MR. MCANDREWS: So I'm going to hand you what  
10 we've marked as Exhibit 28.

11 THE WITNESS: Thank you.

12 MR. MCANDREWS: It is U.S. Patent  
13 No. 7,269,208, naming Simone Mazzoni as the first  
14 named inventor.

15 Q Dr. Jacobsen, is Exhibit 28 the prior art  
16 reference that you rely on in your opening and reply  
17 expert reports for invalidity of the Family 3 patents?

18 **A It is one of them, yes.**

19 Q Okay. And if I refer to this as the Mazzoni  
20 reference, you'd understand that I'm referring to the  
21 '208 patent?

22 **A Yes.**

23 Q Do you know either of the named inventors?

24 **A I don't think so.**

25 Q Okay. Do you recall either of the named

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1 Q No.

2 So -- so the -- and I understand.

3 So without getting into whether the claims  
4 are supported by any particular filing, what is the  
5 earliest filing date that the '208 patent claims  
6 priority to, whether U.S. or foreign?

7 **A It looks like July 18th, 2000.**

8 Q Okay. So assuming that the disclosure in  
9 this reference is effectively unchanged, except  
10 possibly a translation from French to English, is  
11 it -- is it true then that this disclosure, at the  
12 time it was filed, would be viewed in the context of  
13 the DSL art as it existed in July 18, 2000?

14 **A Could you repeat your question. I'm not sure  
15 I got it.**

16 Q So -- so the disclosure provided in the  
17 Mazzoni reference, isn't it true that it would be  
18 interpreted in view of the knowledge of one of skill  
19 in the art at the time of July 18, 2000?

20 And -- and I'm trying -- and -- and this is  
21 not a trick question.

22 I understand that, by the time of the filing  
23 of the Patent-in-Suit, which has -- has its own  
24 priority date, there's going to be additional  
25 information that one of skill in the art learns.

17 (Pages 479 to 482)



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<p style="text-align: right;">Page 483</p> <p>1 But I'm talking about if we're just -- if</p> <p>2 we're worried about -- let's say we were worried about</p> <p>3 what the actual priority date of Mazzoni is, and</p> <p>4 Mazzoni is going to litigate his own patent. And I'm</p> <p>5 talking about the priority date of Mazzoni's patent.</p> <p>6 Isn't it true that Mazzoni's disclosure for</p> <p>7 what it teaches to one of skill in the art at the</p> <p>8 time, wouldn't it -- what -- what -- I'm sorry. Let</p> <p>9 me start over.</p> <p>10 Isn't it true that -- that Mazzoni's priority</p> <p>11 date would be based on what he discloses to one of</p> <p>12 ordinary skill in the art as of July 18, 2000?</p> <p>13 MS. WALSH: Objection; calls for a legal</p> <p>14 conclusion.</p> <p>15 THE WITNESS: Yeah, I'm not sure I'm in a</p> <p>16 position to -- to say.</p> <p>17 MR. MCANDREWS: Okay. Let me try this a</p> <p>18 different way.</p> <p>19 Q So Mazzoni in column 1, beginning at about</p> <p>20 line 19, says:</p> <p>21 "The present invention may advantageously be</p> <p>22 applied to a very high rate digital subscriber line</p> <p>23 (VDSL) environment or system, for example, though the</p> <p>24 invention may also be used in other applications."</p> <p>25 Do you see that?</p>	<p style="text-align: right;">Page 485</p> <p>1 <b>defined for both.</b></p> <p>2 Q And what documents would one of skill in the</p> <p>3 art at that time have found in those schemes?</p> <p>4 <b>A So at that time, there would have been</b></p> <p>5 <b>publicly available T1/E1.4 documents. The DMT group</b></p> <p>6 <b>was called the VDSL Alliance, and the single carrier</b></p> <p>7 <b>group was called the VDSL Coalition. So that's where</b></p> <p>8 <b>a person of ordinary skill would go look. They'd go</b></p> <p>9 <b>look for documents by those two groups.</b></p> <p>10 Q Okay. So -- and in what time frame?</p> <p>11 So as of July 18, 2000, you think those were</p> <p>12 available --</p> <p>13 <b>A Yes.</b></p> <p>14 Q -- publicly?</p> <p>15 <b>A Yes.</b></p> <p>16 Q Okay. The implementation details of the</p> <p>17 initialization process that is found in those, is that</p> <p>18 exactly what was ultimately used in 993.1, the version</p> <p>19 dated in 2004 that you rely on?</p> <p>20 <b>A I don't know for sure. But the -- the</b></p> <p>21 <b>members, if -- if you will, or the participants in the</b></p> <p>22 <b>VDSL Alliance, for example, were the same people who</b></p> <p>23 <b>were participating in the development of G.993.1. So</b></p> <p>24 <b>it wouldn't surprise me if it -- if it ended up being</b></p> <p>25 <b>exactly what had been disclosed there. It might have</b></p>
<p style="text-align: right;">Page 484</p> <p>1 <b>A I do.</b></p> <p>2 Q Okay. So VDSL, as it existed in July 18,</p> <p>3 2000, was not yet a well-defined concept; correct?</p> <p>4 <b>A Well, I'm not sure I would agree with you</b></p> <p>5 <b>there. It had been discussed a lot in the standards</b></p> <p>6 <b>bodies. What was not clear is what line code it was</b></p> <p>7 <b>going to use, whether it would be single carrier or</b></p> <p>8 <b>multi-carrier.</b></p> <p>9 <b>But for example, there had been studies on</b></p> <p>10 <b>the -- what the power spectrum should look like, for</b></p> <p>11 <b>example, and what kinds of data rates would need to be</b></p> <p>12 <b>supported, and whether it would be only asymmetrical,</b></p> <p>13 <b>or asymmetrical plus symmetrical, or something in</b></p> <p>14 <b>between.</b></p> <p>15 <b>So there were a lot of system requirements</b></p> <p>16 <b>laid out, the assumption being that the line code</b></p> <p>17 <b>selection could be put off. Much -- much of it could</b></p> <p>18 <b>be defined without that level of detail.</b></p> <p>19 Q Okay. So for example, as of July 2000 -- as</p> <p>20 of July 2000, had the specific details of the</p> <p>21 initialization process of VDSL been completed?</p> <p>22 <b>A Yes, in two tracks. There were -- there was</b></p> <p>23 <b>the single carrier camp plowing away on their version</b></p> <p>24 <b>of VDSL, and then there was the DMT camp also doing</b></p> <p>25 <b>the same. So there were initialization schemes</b></p>	<p style="text-align: right;">Page 486</p> <p>1 <b>been based on that and modified somewhat. I -- I</b></p> <p>2 <b>don't remember.</b></p> <p>3 Q Okay. And -- and you don't know any of the</p> <p>4 specific changes that were made between the 993.1</p> <p>5 version that you rely on and -- and any version that</p> <p>6 existed as of July 2000?</p> <p>7 <b>A I would have to look at them.</b></p> <p>8 Q Okay.</p> <p>9 <b>A I would have to compare. I have not</b></p> <p>10 <b>compared.</b></p> <p>11 Q And you didn't do that for the purpose of</p> <p>12 your opinion in the case?</p> <p>13 <b>A I did not.</b></p> <p>14 Q Okay. And given that Mazzoni's disclosure</p> <p>15 refers generically to VDSL, without referencing any</p> <p>16 particular standards body or standards document, one</p> <p>17 of skill in the art reading this document, Mazzoni,</p> <p>18 would not know which one, if any of those, Mazzoni</p> <p>19 intended; correct?</p> <p>20 MS. WALSH: Objection; incomplete</p> <p>21 hypothetical.</p> <p>22 THE WITNESS: When you say "which one," what</p> <p>23 are you referring to?</p> <p>24 MR. MCANDREWS: Well, so you referenced that</p> <p>25 there were publications about VDSL as of this date.</p>

18 (Pages 483 to 486)

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<p style="text-align: right;">Page 487</p> <p>1 And apparently, although you haven't described them as</p> <p>2 part of the case, there were initialization processes</p> <p>3 proposed at that time.</p> <p>4 Q To the extent that that's true, you wouldn't</p> <p>5 know, from reading Mazzoni, which, if any of those, he</p> <p>6 had in mind; correct?</p> <p>7 A You wouldn't. But you also wouldn't need to</p> <p>8 know, because what he's talking about is -- is that</p> <p>9 the higher layer than the initialization would be</p> <p>10 conducted.</p> <p>11 Q Okay. Isn't it possible -- so you referenced</p> <p>12 some work that you did with Amati, that was a</p> <p>13 proprietary version --</p> <p>14 A Uh-huh.</p> <p>15 Q -- of VDSL; correct?</p> <p>16 A Yes.</p> <p>17 Q Okay. Isn't it possible that Mazzoni at</p> <p>18 STMicroelectronics had a version of VDSL in mind, that</p> <p>19 was not going to follow any particular standard, even</p> <p>20 the draft ones that were proposed at the time?</p> <p>21 A I think that's unlikely, because VDSL started</p> <p>22 out as a -- a standard. It was proposed in the</p> <p>23 standard. So I don't think that he would have thought</p> <p>24 he had a proprietary implementation.</p> <p>25 Q Well, you said that Amati had a proprietary</p>	<p style="text-align: right;">Page 489</p> <p>1 But that dispute has a huge impact in a lot</p> <p>2 of ways at the physical layer -- at the lowest part of</p> <p>3 the physical layer.</p> <p>4 But there are things that both kinds of</p> <p>5 solutions would need to do that would be common, and</p> <p>6 those are the kinds of things that typically were</p> <p>7 discussed.</p> <p>8 MR. MCANDREWS: Well, you're saying that --</p> <p>9 you're saying those would need to do.</p> <p>10 Q But you agree with me that the -- the</p> <p>11 standards process was in flux?</p> <p>12 A In many respects, it was.</p> <p>13 Q And particularly as of July 2000; correct?</p> <p>14 A There was no line code decision at that</p> <p>15 point.</p> <p>16 Q And -- and there's -- there's no reason why</p> <p>17 Mazzoni, at that time, could not have been</p> <p>18 contemplating his own proprietary version of VDSL;</p> <p>19 right?</p> <p>20 A The fact that he refers to VDSL suggests an</p> <p>21 awareness of the standards process.</p> <p>22 And the fact that he doesn't mention, at</p> <p>23 least I didn't think he mentioned, the line code for</p> <p>24 which he's proposing this approach, suggests to me</p> <p>25 that it's a -- an approach that is not tied to the</p>
<p style="text-align: right;">Page 488</p> <p>1 implementation.</p> <p>2 Is there some reason why STMicroelectronics</p> <p>3 could not?</p> <p>4 Did -- did Amati have a monopoly on that</p> <p>5 market?</p> <p>6 A No. When I said we have a -- had a</p> <p>7 proprietary solution, it was because we were proposing</p> <p>8 it for the standard. We created it. We built it to</p> <p>9 show that it would work. And in parallel, we proposed</p> <p>10 it in the standards bodies. And presumably, ST was</p> <p>11 maybe doing the same thing.</p> <p>12 Q Okay. But given that VDSL1 continued to be</p> <p>13 developed through at least 2004, and VDSL2 continued</p> <p>14 to be developed -- well, it's currently being</p> <p>15 developed, but the first version was -- was approved</p> <p>16 in 2006, isn't it possible that he was also going to</p> <p>17 be proposing ideas for those standards that were</p> <p>18 different than those already proposed?</p> <p>19 MS. WALSH: Objection; incomplete</p> <p>20 hypothetical.</p> <p>21 THE WITNESS: It's possible.</p> <p>22 But again, the -- the key dispute in VDSL,</p> <p>23 and the reason why it took so long, was because</p> <p>24 there -- there was no agreement on the line code,</p> <p>25 whether it was DMT or -- or single carrier.</p>	<p style="text-align: right;">Page 490</p> <p>1 issues that were in flux at the time.</p> <p>2 Q Okay. So he could have been contemplating</p> <p>3 either the capped version or the DMT version, for</p> <p>4 example; right?</p> <p>5 A He could have been.</p> <p>6 Q Okay. And -- and I think you said before</p> <p>7 that there is a different initialization process,</p> <p>8 depending on which one you have; right?</p> <p>9 A There are some different aspects, yes.</p> <p>10 Q Okay. And given that the final</p> <p>11 implementation details of any particular VDSL standard</p> <p>12 were still in flux at this time, you're not saying</p> <p>13 that STMicroelectronics wouldn't be allowed to propose</p> <p>14 changes to the standards; right?</p> <p>15 A I am not saying that.</p> <p>16 Q Okay. So they certainly could have been</p> <p>17 coming up with some implementation details of their</p> <p>18 own, that they could have kept as pri- -- proprietary,</p> <p>19 or they could have been proposing to the -- the</p> <p>20 development of the VD -- the ITU VDSL standards;</p> <p>21 correct?</p> <p>22 MS. WALSH: Objection; compound; calls for</p> <p>23 speculation.</p> <p>24 THE WITNESS: I don't know what they did.</p> <p>25 MR. MCANDREWS: Okay.</p>

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<p style="text-align: right;">Page 491</p> <p>1 Q So let's talk about Mazzoni in particular</p> <p>2 now.</p> <p>3 So you have some opinions about Mazzoni. If</p> <p>4 you want to refer to those aspects of your written</p> <p>5 reports, please do.</p> <p>6 So one thing that I want to -- I want to nail</p> <p>7 down -- because there seems to be disagreement over</p> <p>8 what your position was in the opening report. And as</p> <p>9 you may know, in our view, there was even some</p> <p>10 conflict in your opening report on the topic.</p> <p>11 But the issue is the I and M parameters that</p> <p>12 are used by -- by Mazzoni.</p> <p>13 Dr. Cooklev had interpreted your opening</p> <p>14 report as suggesting that the I and M parameters are</p> <p>15 something that is exchanged between the transceivers</p> <p>16 in Mazzoni's system during some theoretical</p> <p>17 initialization process.</p> <p>18 Do you recall that in Dr. Cooklev's report?</p> <p>19 <b>A I don't specifically recall that. But I</b></p> <p>20 <b>don't believe that that was how I characterized</b></p> <p>21 <b>Mazzoni.</b></p> <p>22 Q Okay. So -- so let me ask you -- since --</p> <p>23 since there seems to be some confusion, I want to -- I</p> <p>24 want to tamp it down and put it to rest.</p> <p>25 Do you believe that Mazzoni discloses</p>	<p style="text-align: right;">Page 493</p> <p>1 <b>combi- -- combinations and six symmetric bit rate --</b></p> <p>2 <b>bit rates, I believe.</b></p> <p>3 Q Okay. And I think he refers to those as --</p> <p>4 for the asymmetric, it's A1 through A6; is that right?</p> <p>5 <b>A I believe that is right.</b></p> <p>6 Q I think, if you look at the top of column 4,</p> <p>7 you might find that.</p> <p>8 <b>A (Witness complies.)</b></p> <p>9 <b>Right.</b></p> <p>10 Q Okay. And there are also six symmetrical</p> <p>11 services, S1 through S6, that I think you can find at</p> <p>12 the bottom of column 3.</p> <p>13 <b>A That's right.</b></p> <p>14 Q Okay. And each service is defined as a -- an</p> <p>15 upstream bit rate and a downstream bit rate; is that</p> <p>16 correct?</p> <p>17 <b>A I believe that is correct.</b></p> <p>18 Q Okay. And then, so would it be your</p> <p>19 understanding that, for each of the 12 services, there</p> <p>20 is a corresponding I, M, I prime, and M prime that is</p> <p>21 stored in Mazzoni's table?</p> <p>22 <b>A That is my understanding of -- of the</b></p> <p>23 <b>preferred embodiment.</b></p> <p>24 Q Okay. And Mazzoni also then explains how</p> <p>25 much memory for interleaving and de-interleaving it</p>
<p style="text-align: right;">Page 492</p> <p>1 exchanging I and M parameters during initialization?</p> <p>2 <b>A I believe my opinion was and has always been</b></p> <p>3 <b>that Mazzoni stores particular values of I and M and</b></p> <p>4 <b>I prime and M prime in a table.</b></p> <p>5 Q Okay. And -- and --</p> <p>6 <b>A I'm trying to --</b></p> <p>7 Q -- at the bottom of column 6, I think, is</p> <p>8 maybe what you're referencing.</p> <p>9 <b>A (Witness complies.)</b></p> <p>10 <b>That's right.</b></p> <p>11 Q Okay. So I -- so the I and M values, and the</p> <p>12 I prime and M prime values that will be used by</p> <p>13 Mazzoni's device, they're stored in a table; correct?</p> <p>14 <b>A The understanding that I have is that in</b></p> <p>15 <b>advance, Mazzoni defines particular services, and for</b></p> <p>16 <b>each one, at least one set of I, M, I prime, M prime,</b></p> <p>17 <b>and then stores a table with those sets of parameters.</b></p> <p>18 Q Okay. And -- and those sets of parameters</p> <p>19 are indexed per service?</p> <p>20 <b>A I believe it's per bit rate combination</b></p> <p>21 <b>within the service, or per downstream bit rate and</b></p> <p>22 <b>upstream bit rate.</b></p> <p>23 Q Okay. And the -- and the services that</p> <p>24 Mazzoni describes, there's 12 of them; is that right?</p> <p>25 <b>A I'm -- he describes six asymmetric bit rate</b></p>	<p style="text-align: right;">Page 494</p> <p>1 will require, depending on the service; is that</p> <p>2 correct?</p> <p>3 <b>A I believe Mazzoni discloses figuring out the</b></p> <p>4 <b>maximum that you might need, based on the services to</b></p> <p>5 <b>be provided. And then that's how he figures out how</b></p> <p>6 <b>much memory the transceiver must have.</b></p> <p>7 Q So for example, if we look at the top of</p> <p>8 column 6, and really run -- so running from about --</p> <p>9 well, running almost nearly the entire length of</p> <p>10 column 6, from the top down through line 51 that we</p> <p>11 were talking about earlier about the tables.</p> <p>12 So the paragraph that begins at 51 is the</p> <p>13 tables; right?</p> <p>14 <b>A Correct.</b></p> <p>15 Q Okay. So -- so column 6 is describing the</p> <p>16 manner in which Mazzoni determines the amount of</p> <p>17 memory that will be required to support any particular</p> <p>18 service; correct?</p> <p>19 <b>A I believe he's figuring out the amount of</b></p> <p>20 <b>memory that must be included in order to support the</b></p> <p>21 <b>service that requires the most memory --</b></p> <p>22 <b>Q Okay.</b></p> <p>23 <b>A -- for interleaving and de-inter- --</b></p> <p>24 <b>de-interleaving.</b></p> <p>25 Q Okay. And we can step through this in a</p>

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<p style="text-align: right;">Page 495</p> <p>1 little more detail.</p> <p>2 But do you recall, at least, that Dr. Cooklev</p> <p>3 concluded, that the amount of memory required in the</p> <p>4 Mazzoni-described device, would be dependent on the</p> <p>5 amount of memory required for the highest asymmetrical</p> <p>6 service?</p> <p>7 <b>A I don't specifically recall that.</b></p> <p>8 Q Okay. So -- so let me -- so essentially,</p> <p>9 what Mazzoni is describing -- and you can tell me if</p> <p>10 you think I'm incorrect, or if you don't have an</p> <p>11 understanding one way or the other.</p> <p>12 Mazzoni is describing that -- first of all,</p> <p>13 he explains that for -- and this is beginning at</p> <p>14 column 6, line 11, and then concluding at about</p> <p>15 line 30.</p> <p>16 Mazzoni is describing the amount of memory</p> <p>17 that is required for the downstream direction in his</p> <p>18 A6 service, where he concludes that the resulting</p> <p>19 memory space is therefore equal to 24,960 bytes.</p> <p>20 Do you see that?</p> <p>21 <b>A I do.</b></p> <p>22 Q Do you recall, is that consistent with your</p> <p>23 recollection of what Mazzoni is doing there to arrive</p> <p>24 at the 24,960-byte number?</p> <p>25 <b>A My understanding is that he's figuring out</b></p>	<p style="text-align: right;">Page 497</p> <p>1 is the most that will ever be needed to support any of</p> <p>2 the 12 services; right?</p> <p>3 <b>A That's my understanding of this example, yes.</b></p> <p>4 Q Okay. So for example, the S6 service, so the</p> <p>5 symmetrical service with the highest data rate -- and</p> <p>6 I don't know that Mazzoni necessarily does the</p> <p>7 calculations. I think that Dr. Cooklev may have done</p> <p>8 the calculations using the equations that Mazzoni</p> <p>9 describes.</p> <p>10 But essentially, what Dr. Cooklev concluded</p> <p>11 is that, for the symmetrical service, approximately</p> <p>12 11,000 bytes would be required for each direction.</p> <p>13 Do you have any reason to believe that that's</p> <p>14 not an accurate calculation for the -- for the S6</p> <p>15 service?</p> <p>16 <b>A I did not do the calculation myself, so I --</b></p> <p>17 <b>I don't -- I don't know.</b></p> <p>18 MR. MCANDREWS: Okay. We need to go off the</p> <p>19 record here for a minute to change tape.</p> <p>20 THE VIDEOGRAPHER: This marks the end of</p> <p>21 Videotape No. 1, Volume III, in the deposition of</p> <p>22 Dr. Krista Jacobsen.</p> <p>23 The time is now 11:19. Going off the record.</p> <p>24 (Recess taken.)</p> <p>25 THE VIDEOGRAPHER: Going on the record.</p>
<p style="text-align: right;">Page 496</p> <p>1 <b>worst case how much memory he needs for downstream.</b></p> <p>2 Q "Worst case" being the A6 service?</p> <p>3 <b>A The highest bit rate service.</b></p> <p>4 Q Okay. And then the next paragraph, beginning</p> <p>5 at about line 31, and going through line 36 of</p> <p>6 column 6, he explains that an additional 1,920 bytes</p> <p>7 are needed for the upstream direction in the A6</p> <p>8 service?</p> <p>9 <b>A That's my understanding.</b></p> <p>10 Q Okay. And so that means that the total</p> <p>11 amount of memory, that the Mazzoni device will require</p> <p>12 to support the A6 service, is 26,880 bytes.</p> <p>13 Do you see that?</p> <p>14 <b>A Yes.</b></p> <p>15 Q Okay. And is it your understanding of the</p> <p>16 Mazzoni reference then that the device would be</p> <p>17 provided with approximately 26,880 bytes of memory,</p> <p>18 and then, depending on the service, that memory would</p> <p>19 be used for either interleaving or de-interleaving?</p> <p>20 <b>A That -- my understanding is that the purpose</b></p> <p>21 <b>of this analysis in Mazzoni is to figure out the size</b></p> <p>22 <b>of the memory needed. And then the memory would</b></p> <p>23 <b>actually be allocated for interleaving and</b></p> <p>24 <b>de-interleaving, depending on which service is in use.</b></p> <p>25 Q Okay. And -- and the idea is that the 26,880</p>	<p style="text-align: right;">Page 498</p> <p>1 This marks the beginning of Videotape No. 2,</p> <p>2 Volume III, in the deposition of Dr. Krista Jacobsen.</p> <p>3 The time is now 11:30.</p> <p>4 MR. MCANDREWS: Q. So before the -- the</p> <p>5 break there, we were talking about some specific</p> <p>6 amounts of memory that Mazzoni is using for the</p> <p>7 various services.</p> <p>8 And I don't want to get bogged down in the</p> <p>9 precise numbers of bytes, because I don't think that's</p> <p>10 the important point that I'm trying to explore here.</p> <p>11 So -- because I don't think they're necessary to the</p> <p>12 point.</p> <p>13 So -- so let me -- let me just -- let's --</p> <p>14 let's set up a Mazzoni device, and you can tell me if</p> <p>15 there's something that is wildly misrepresenting</p> <p>16 Mazzoni or misrepresenting Mazzoni.</p> <p>17 But -- so let's assume that Mazzoni has --</p> <p>18 and I'll use round numbers -- has 27,000 bytes of</p> <p>19 memory that is necessary for the A6 service; okay?</p> <p>20 <b>A Okay.</b></p> <p>21 Q Okay. And that no other of the</p> <p>22 11 services -- or no other of the 12 total services</p> <p>23 requires any more than 27,000 bytes of memory.</p> <p>24 <b>A Okay.</b></p> <p>25 Q Okay. And let's also assume that the S6</p>

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<p style="text-align: right;">Page 499</p> <p>1 service requires 11,000 bytes in each direction, for a</p> <p>2 total of 22,000 bytes.</p> <p>3 <b>A Okay.</b></p> <p>4 Q And so given that setup, I want to talk about</p> <p>5 an aspect of your report, where Doctor -- where you're</p> <p>6 responding to Dr. Cooklev's argument that, if all of</p> <p>7 the devices exchanged with each other was the maximum</p> <p>8 amount of memory that either device had to support in</p> <p>9 a particular direction, that that would essentially</p> <p>10 break Mazzoni.</p> <p>11 Do you recall Dr. Cooklev's argument?</p> <p>12 <b>A I recall it generally, but I don't recall the</b></p> <p>13 <b>specifics. I would have to look at my report.</b></p> <p>14 Q Okay. So -- and let me -- let me -- one part</p> <p>15 of the -- the -- the scenario I set up, I forgot to</p> <p>16 say that, let's assume that in the A6 service, the</p> <p>17 downstream direction requires 26,000 -- or let's go</p> <p>18 with 25,000. Let's go with 25,000, that the A6</p> <p>19 service requires 25,000 of the 27,000 total bytes of</p> <p>20 memory available.</p> <p>21 <b>A Okay.</b></p> <p>22 Q Okay. So if, hypothetically, the LB-031</p> <p>23 messaging scheme was added to Mazzoni -- and that's --</p> <p>24 that's a prior art combination that you suggest</p> <p>25 renders the claims obvious; correct?</p>	<p style="text-align: right;">Page 501</p> <p>1 THE REPORTER: 29.</p> <p>2 MR. MCANDREWS: 29, I believe.</p> <p>3 THE REPORTER: 29. Correct.</p> <p>4 (Document marked Exhibit 29</p> <p>5 for identification.)</p> <p>6 MR. MCANDREWS: So I'm going to hand you what</p> <p>7 we've marked as Exhibit No. 29. Exhibit 29 is a</p> <p>8 document entitled:</p> <p>9 ITU - Telecommunications Sector" --</p> <p>10 I'm sorry. Let me start over.</p> <p>11 "ITU - Telecommunications Standardization</p> <p>12 Sector, Study Group 15, Luven, 14-18 June, 2004.</p> <p>13 Temporary Document LB-031."</p> <p>14 Q Did I accurately describe that document?</p> <p>15 <b>A That is correct.</b></p> <p>16 Q Okay. And can we refer to this document as</p> <p>17 LB-031?</p> <p>18 <b>A Yes.</b></p> <p>19 Q Can you tell me generally what -- what LB-031</p> <p>20 is?</p> <p>21 <b>A Sure.</b></p> <p>22 <b>This was a contribution to a meeting of Study</b></p> <p>23 <b>Group 15, Question 4 in June of 2004. And that was</b></p> <p>24 <b>the group that was standardizing -- well, primarily</b></p> <p>25 <b>responsible for standardizing ADSL, VDSL, and other</b></p>
<p style="text-align: right;">Page 500</p> <p>1 <b>A Right.</b></p> <p>2 Q Okay. So if LB-031 was added, and therefore,</p> <p>3 what was exchanged was only the maximum capability of</p> <p>4 each device in a given direction, and so what was</p> <p>5 exchanged by each side or -- or let's just say what</p> <p>6 was exchanged from Mazzoni's device was, I can support</p> <p>7 up to 25,000 bytes of memory downstream, and I can</p> <p>8 support up to 11 bytes of memory -- 11,000 bytes of</p> <p>9 memory upstream, isn't it true that that device would</p> <p>10 not be able to work, because you would then require a</p> <p>11 total of 36,000 bytes of memory?</p> <p>12 MS. WALSH: Objection; incomplete</p> <p>13 hypothetical.</p> <p>14 THE WITNESS: I'm not sure I understand</p> <p>15 the -- the setup.</p> <p>16 MR. MCANDREWS: Okay.</p> <p>17 Q Can -- can you tell me what you don't</p> <p>18 understand about my setup?</p> <p>19 <b>A I'm not sure -- the -- the LB-031 aspect that</b></p> <p>20 <b>you're introducing, I'm -- I'm not sure I completely</b></p> <p>21 <b>understand what your -- what your hypothetical is.</b></p> <p>22 MR. MCANDREWS: Okay. Can we -- can we get</p> <p>23 the LB-031 reference?</p> <p>24 I'm sorry. What -- what exhibit number are</p> <p>25 we on, if you know?</p>	<p style="text-align: right;">Page 502</p> <p>1 <b>types of DSL.</b></p> <p>2 Q Okay. And there's a -- there's a range of</p> <p>3 dates, I guess, June 14 through 18, 2004.</p> <p>4 What does that mean?</p> <p>5 <b>A That would be the -- the dates of the meeting</b></p> <p>6 <b>at which this contribution was presented, discussed,</b></p> <p>7 <b>submitted.</b></p> <p>8 Q Okay. Do you know if you attended any</p> <p>9 meeting at which LB-031 was discussed?</p> <p>10 <b>A I -- it may have been discussed at one or</b></p> <p>11 <b>more meetings. I don't have any specific recollection</b></p> <p>12 <b>of it.</b></p> <p>13 Q Were you working for TI at this time?</p> <p>14 <b>A No. I had left TI.</b></p> <p>15 Q Okay. Did you have any involvement in the</p> <p>16 creation of this contribution?</p> <p>17 <b>A Not that I recall.</b></p> <p>18 Q Okay. So in -- so you had asked me -- well,</p> <p>19 you had explained that you weren't certain what aspect</p> <p>20 of LB-031 I was referring to.</p> <p>21 And so generally, LB-031 is directed to</p> <p>22 exchanging information during initialization of a</p> <p>23 VDSL2 modem; is that correct?</p> <p>24 <b>A That's right.</b></p> <p>25 Q And is it fair to say that one of the unique</p>



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<p style="text-align: right;">Page 503</p> <p>1 aspects of LB-031 is it's proposing to exchange</p> <p>2 information about milliseconds of delay, as opposed to</p> <p>3 simply, for example, bytes of delay?</p> <p>4 <b>A I don't know that I would say that's</b></p> <p>5 <b>necessarily unique, because the idea of delay being</b></p> <p>6 <b>measured in milliseconds is -- was -- was known.</b></p> <p>7 Q Okay. So that was known as a concept.</p> <p>8 But -- but -- so -- so what is the unique</p> <p>9 aspect, if any, of LB-031?</p> <p>10 <b>A The -- well, I think there are several unique</b></p> <p>11 <b>aspects, among them the idea of, instead of specifying</b></p> <p>12 <b>interleaving complexity as an amount of memory, or by</b></p> <p>13 <b>the interleaver depth, you would specify it in</b></p> <p>14 <b>milliseconds to remove the dependence of the amount of</b></p> <p>15 <b>memory on the data rate that's supported. So you --</b></p> <p>16 <b>you basically cancel that out of the calculation.</b></p> <p>17 <b>And then the idea of sending information from</b></p> <p>18 <b>one transceiver to the other, regarding its</b></p> <p>19 <b>interleaving capabilities, is the other -- one of the</b></p> <p>20 <b>other big ideas.</b></p> <p>21 Q Okay. So -- so let me attempt to</p> <p>22 characterize what some of the information is that is</p> <p>23 exchanged. You tell me if it's accurate.</p> <p>24 So during -- during the initialization</p> <p>25 process, the CO and the CPE would exchange the maximum</p>	<p style="text-align: right;">Page 505</p> <p>1 would then select the smaller of the transmitter and</p> <p>2 receiver capabilities in each direction as the</p> <p>3 end-to-end capabilities."</p> <p>4 Do you see that?</p> <p>5 <b>A I do.</b></p> <p>6 Q Okay. So for example, if Mazzoni was one of</p> <p>7 the two transceivers, if Mazzoni was the VTU-R, for</p> <p>8 example, and Mazzoni says that the maximum I can</p> <p>9 support in the downstream direction is 25,000, and the</p> <p>10 maximum I can support in the upstream direction is</p> <p>11 11,000, and the -- and the other side then specified,</p> <p>12 let's say, those same amounts, 11,000 and 25,000.</p> <p>13 So then the devices select the smaller of the</p> <p>14 transmitter and receiver capabilities. But in this</p> <p>15 case, they agreed they were the same amount. So in</p> <p>16 other words, they would attempt to use 25,000 in the</p> <p>17 downstream direction, and 11,000 in the upstream</p> <p>18 direction.</p> <p>19 Is there something wrong with that scenario?</p> <p>20 <b>A As far as I understand what LB-031 is</b></p> <p>21 <b>proposing, it's -- it's the delay in terms of octets,</b></p> <p>22 <b>which includes the transmitter and receiver, as -- as</b></p> <p>23 <b>we discussed.</b></p> <p>24 Q Okay. So -- so is part of the problem that I</p> <p>25 need to double those numbers?</p>
<p style="text-align: right;">Page 504</p> <p>1 number of bytes of delay that it -- that it can</p> <p>2 support in any particular direction; is that true?</p> <p>3 <b>A It says that the VTU-0 and the VTU-R exchange</b></p> <p>4 <b>the interleaver delay in terms of octets.</b></p> <p>5 Q Okay. And you're referring to, I guess, on</p> <p>6 page 3.</p> <p>7 And let me -- just for -- for the record</p> <p>8 here, so LB-031 was produced at Bates</p> <p>9 No. 2WIRE00030957 through '30963.</p> <p>10 And what I'm referring to is on native</p> <p>11 page 3, Bates No. '30959.</p> <p>12 Were you referring to that paragraph?</p> <p>13 <b>A Yes.</b></p> <p>14 Q Okay. And the paragraph is the</p> <p>15 second-to-last paragraph that appears on that page?</p> <p>16 <b>A That's right.</b></p> <p>17 Q Okay. And that states:</p> <p>18 "For interoperability reasons, the VTU-0 and</p> <p>19 VTU-R must exchange the interleaver delay, in terms of</p> <p>20 octets. The requirement is that the interleaver delay</p> <p>21 and octets be sufficient to satisfy the smallest</p> <p>22 maximum delay, even at the highest supported data</p> <p>23 rate. If a VDSL2 implementation supports a larger</p> <p>24 interleaver memory than is required, it should be free</p> <p>25 to specify the larger value. The VTU-0 and VTU-R</p>	<p style="text-align: right;">Page 506</p> <p>1 So -- so let's say that Mazzoni was going to</p> <p>2 be implementing a triangular interleaver.</p> <p>3 Is it that to support -- Mazzoni would be</p> <p>4 supporting, I guess, 50,000 bytes of delay if he had</p> <p>5 25,000 bytes of memory for the downstream direction?</p> <p>6 Is that the issue with my scenario?</p> <p>7 <b>A Not exactly.</b></p> <p>8 <b>If you look at the example on the next page</b></p> <p>9 <b>of LB-031, I think that helps explain what LB-031 had</b></p> <p>10 <b>in mind.</b></p> <p>11 <b>So he talks about the minimum interleaver</b></p> <p>12 <b>delay requirement being 5.23 milliseconds,</b></p> <p>13 <b>corresponding to a particular delay in octets of</b></p> <p>14 <b>29,092 octets, which means it would need at least half</b></p> <p>15 <b>of that amount of memory.</b></p> <p>16 <b>And then he -- this -- in this example, the</b></p> <p>17 <b>VDSL transceiver would indicate it supports up to this</b></p> <p>18 <b>bit rate and this amount, these 29,092 or more octets</b></p> <p>19 <b>of interleaver delay.</b></p> <p>20 <b>And then the two transceivers would agree on</b></p> <p>21 <b>the bit rates and the actual amount of delay.</b></p> <p>22 Q Okay. But -- but isn't it true that, in</p> <p>23 LB-031, once they have exchanged the maximum that they</p> <p>24 can use in each direction as the end-to-end</p> <p>25 capabilities, that either device, whichever one wants</p>

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<p style="text-align: right;">Page 507</p> <p>1 to make the proposal, can use up to that amount for</p> <p>2 each -- for -- for the direction that it specified</p> <p>3 that amount for?</p> <p>4 <b>A Can you repeat your question?</b></p> <p>5 <b>I'm not sure I understood --</b></p> <p>6 Q Okay. So --</p> <p>7 <b>A -- exactly.</b></p> <p>8 Q -- so once the exchange, that is described on</p> <p>9 page 3 occurs, which is for each device to specify the</p> <p>10 amount of memory that it supports in a given</p> <p>11 direction, and then the two transceivers pick the</p> <p>12 smaller of those capabilities. So you've arrived at a</p> <p>13 number for upstream and a number for downstream. And</p> <p>14 whether that's specified in -- well, I guess it's</p> <p>15 specified in -- in delay in terms of octets.</p> <p>16 Once that's been specified, what will be used</p> <p>17 by the devices is any number up to that amount in each</p> <p>18 direction?</p> <p>19 <b>A So the -- the context of -- of LB-031 is that</b></p> <p>20 <b>one of the two transceivers has more memory than the</b></p> <p>21 <b>other, and they're trying to negotiate parameters that</b></p> <p>22 <b>would work for both of the -- of the transceivers.</b></p> <p>23 <b>The hypothetical you gave me from Mazzoni is</b></p> <p>24 <b>a little bit different, because in that case, you set</b></p> <p>25 <b>it up as the maximum in each direction, without</b></p>	<p style="text-align: right;">Page 509</p> <p>1 direction independently, you don't disagree with</p> <p>2 Dr. Cooklev that that would not work with Mazzoni;</p> <p>3 correct?</p> <p>4 <b>A I don't think that's what LB031 suggests</b></p> <p>5 <b>doing.</b></p> <p>6 Q What do you mean?</p> <p>7 That's -- I mean, that's exactly what it says</p> <p>8 it's doing on page 3.</p> <p>9 And -- and I know you have an opinion about</p> <p>10 what it might suggest to one of skill in the art, but</p> <p>11 let's -- can we -- can we set that aside?</p> <p>12 I want to talk about the specific example.</p> <p>13 <b>A Right.</b></p> <p>14 Q Because you have -- you have a disagreement</p> <p>15 with it, I want to try to understand the basis for</p> <p>16 your disagreement, where you call his argument</p> <p>17 specious. I'm trying to -- I'm trying to get to that</p> <p>18 point.</p> <p>19 And on page 111, you seem to be suggesting</p> <p>20 that it's specious -- specious because it would be</p> <p>21 trivial to select a different size memory; okay?</p> <p>22 So -- so to get to that point, it sounds like</p> <p>23 you agree that, if you literally used only messaging</p> <p>24 that said, "This is my maximum downstream, and this is</p> <p>25 my maximum upstream," and then the devices could use</p>
<p style="text-align: right;">Page 508</p> <p>1 <b>consideration of the fact that that total exceeds</b></p> <p>2 <b>the -- the total that they have.</b></p> <p>3 <b>So I don't think that hypothetical works.</b></p> <p>4 Q Correct. And that was our point -- that was</p> <p>5 Dr. Cooklev's point, and you said that his argument</p> <p>6 was specious.</p> <p>7 <b>A And where is -- where is this?</b></p> <p>8 Q This is in the middle of page 111, for</p> <p>9 example, in your expert reply report. You state:</p> <p>10 "This argument is specious because it would</p> <p>11 be trivial to one of ordinary skill in the art to</p> <p>12 select a different size memory for the</p> <p>13 interleaver/de-interleaver pair."</p> <p>14 <b>A Right.</b></p> <p>15 <b>And I think what I was referring to here is</b></p> <p>16 <b>that the Mazzoni VTU-0 would not receive this message</b></p> <p>17 <b>having 2- -- sorry -- 24,960 bytes and 10,860 bytes,</b></p> <p>18 <b>because that would exceed the total amount of memory</b></p> <p>19 <b>available.</b></p> <p>20 Q Right.</p> <p>21 So you -- but -- so you don't disagree that,</p> <p>22 if Mazzoni tried to use what LB-031 was contemplating,</p> <p>23 you don't disagree that -- you -- I'm sorry.</p> <p>24 If Mazzoni used LB031's messages that simply</p> <p>25 exchanged the maximum that was available for each</p>	<p style="text-align: right;">Page 510</p> <p>1 up to that amount, it sounds like you don't challenge</p> <p>2 Dr. Cooklev's argument that that wouldn't work with</p> <p>3 Mazzoni; correct?</p> <p>4 <b>A I don't think that would work, but I also</b></p> <p>5 <b>don't think that that's what LB-031 suggests doing.</b></p> <p>6 Q Okay. Let me -- let me stop there. So --</p> <p>7 and we can get to that in a minute.</p> <p>8 But that wasn't your response in your reply.</p> <p>9 Your response was not that that's not what LB-031</p> <p>10 teaches me. Your response was:</p> <p>11 "That argument is specious because it would</p> <p>12 be trivial to select a different size memory."</p> <p>13 And I want to understand what you mean by</p> <p>14 that.</p> <p>15 <b>A Well, I think, as I interpreted his argument</b></p> <p>16 <b>here, he was assuming that the Mazzoni memory would</b></p> <p>17 <b>always be limited to this -- whatever it turned out to</b></p> <p>18 <b>be, 26,880 bytes.</b></p> <p>19 Q Okay.</p> <p>20 <b>A And -- and that I don't think is true if -- a</b></p> <p>21 <b>person having ordinary skill reading Mazzoni would</b></p> <p>22 <b>understand that, if there were higher bit rate</b></p> <p>23 <b>services defined, for example, that that size memory</b></p> <p>24 <b>would increase.</b></p> <p>25 Q Okay. So let me understand that.</p>

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<p style="text-align: right;">Page 511</p> <p>1 So Mazzoni does not describe higher bit rate</p> <p>2 services; right?</p> <p>3 <b>A Not explicitly.</b></p> <p>4 Q Okay. In fact, one of the benefits of</p> <p>5 Mazzoni is that he only has to have 27,000 bytes of</p> <p>6 memory total to support each of his 12 services;</p> <p>7 right?</p> <p>8 <b>A He discloses minimizing the amount of memory</b></p> <p>9 <b>necessary for interleaving and de-interleaving.</b></p> <p>10 Q Okay. So -- so given -- given the numbers we</p> <p>11 talked through before -- let me -- let me do them</p> <p>12 again.</p> <p>13 So we -- so the argument was, there are</p> <p>14 27,000 total bytes of memory. There -- there's 25,000</p> <p>15 required for downstream and 11,000 required for</p> <p>16 upstream; right?</p> <p>17 And so if you -- if you attempted to use that</p> <p>18 maximum capability in both directions, 27,000 bytes of</p> <p>19 memory is not enough; right?</p> <p>20 <b>A Right.</b></p> <p>21 <b>But you would never have those two at the</b></p> <p>22 <b>same time.</b></p> <p>23 Q Right.</p> <p>24 But if all you got was the message from</p> <p>25 LB-031 that said, "This is my maximum downstream, and</p>	<p style="text-align: right;">Page 513</p> <p>1 <b>deployed, but before it's deployed.</b></p> <p>2 Q So when you design it, you put in</p> <p>3 36,000 bytes of memory.</p> <p>4 Is that -- that's the idea?</p> <p>5 <b>A That would be one way.</b></p> <p>6 Q Okay. But then haven't you just eliminated</p> <p>7 any need to share memory?</p> <p>8 Because now you have the full capability for</p> <p>9 downstream, and you have the full capability of</p> <p>10 upstream. And therefore, there's no more need to</p> <p>11 share memory; right?</p> <p>12 <b>A But then you could -- you would recognize</b></p> <p>13 <b>that you could do additional services as well.</b></p> <p>14 Q But then we're just upping it, and we're</p> <p>15 running into further problems; right?</p> <p>16 I mean, if you want to just keep expanding</p> <p>17 it, the problem just keeps growing and growing; right?</p> <p>18 <b>A It would depend on how it was implemented.</b></p> <p>19 Q Okay. And then -- and then the other thing</p> <p>20 that you've done, now you've eliminated any need to</p> <p>21 share memory, but you've also increased the amount of</p> <p>22 memory and eliminated the benefit of memory sharing;</p> <p>23 correct?</p> <p>24 <b>A You haven't eliminated it, because you're</b></p> <p>25 <b>able to support higher rate services.</b></p>
<p style="text-align: right;">Page 512</p> <p>1 this is my maximum upstream," and each device was</p> <p>2 allowed to use up to that amount, then isn't it true</p> <p>3 that it would require 36,000 bytes of memory, and it</p> <p>4 doesn't have that? Right?</p> <p>5 <b>A Well, again, I'm not sure I agree with your</b></p> <p>6 <b>characterization of LB-031.</b></p> <p>7 <b>But it is true that, if you were to specify a</b></p> <p>8 <b>total that exceeded the capacity of the -- the memory,</b></p> <p>9 <b>then there will be a problem.</b></p> <p>10 Q Okay. But -- and then -- so your solution to</p> <p>11 that, though, is that it would be trivial to one of</p> <p>12 skill in the art to select a different size memory for</p> <p>13 the interleaver/de-interleaver pair.</p> <p>14 So is your argument there that you would then</p> <p>15 simply select 36,000 bytes of memory to put into</p> <p>16 Mazzoni?</p> <p>17 <b>A That -- how I interpreted Dr. Cooklev's</b></p> <p>18 <b>argument there -- and maybe I misinterpreted it, but I</b></p> <p>19 <b>interpreted his argument as being that that total</b></p> <p>20 <b>exceeds the total disclosed in Mazzoni.</b></p> <p>21 Q Right.</p> <p>22 And you're saying it would be trivial to</p> <p>23 simply up it to 36,000.</p> <p>24 Is that the argument?</p> <p>25 <b>A Not when you're actually -- not after it's</b></p>	<p style="text-align: right;">Page 514</p> <p>1 Q But if -- but if you have higher rate</p> <p>2 services, then you're not going to -- then you're</p> <p>3 going to need more than 36,000?</p> <p>4 <b>A But not if you -- not if the capabilities</b></p> <p>5 <b>exchanged are compatible with each other.</b></p> <p>6 Q And the capabilities exchanged, that you're</p> <p>7 attempting to describe here, is something other than</p> <p>8 what LB-031 describes; right?</p> <p>9 <b>A I'm not sure I agree with you on that.</b></p> <p>10 Q Okay. So let's -- let me try to put this to</p> <p>11 rest, though.</p> <p>12 So wasn't your argument that you -- that the</p> <p>13 trivial part that you describe on page 111, the</p> <p>14 trivial part that you're describing there is -- is</p> <p>15 simply that you would increase the amount of memory to</p> <p>16 36,000?</p> <p>17 <b>A Well, it -- the -- the particular point I was</b></p> <p>18 <b>making here is that end to end, you would need</b></p> <p>19 <b>potentially more, because again, it's the interleaver</b></p> <p>20 <b>in one and the de-interleaver in the other. But you</b></p> <p>21 <b>would adjust the memory -- the amount of memory in one</b></p> <p>22 <b>or both of them.</b></p> <p>23 Q By increasing it?</p> <p>24 <b>A Yes.</b></p> <p>25 Q Right.</p>



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<p style="text-align: right;">Page 515</p> <p>1 And therefore, if you increase it to the</p> <p>2 point where you can support the maximum downstream and</p> <p>3 the maximum upstream at the same time, there's no</p> <p>4 longer any need to share memory. You could partition</p> <p>5 that and make dedicated de-interleaver memory and</p> <p>6 dedicated interleaver memory; correct?</p> <p>7 <b>A You could.</b></p> <p>8 <b>But Mazzoni describes partitioning it</b></p> <p>9 <b>after -- after the connection is being initialized.</b></p> <p>10 Q Okay. I'm going to -- I'm going to come back</p> <p>11 to that as well.</p> <p>12 So you -- you seem to think that you</p> <p>13 partition it after it's initialized, although Mazzoni</p> <p>14 describes that as happening at installation. So let</p> <p>15 me mark that down as a point to go back to.</p> <p>16 But let's -- as -- as long as we've got it</p> <p>17 out here, let's talk about LB-031.</p> <p>18 So where is it that you -- you, in any of</p> <p>19 your reports, explain that LB-031 is exchanging any</p> <p>20 messages, other than the maximum supported</p> <p>21 independently in each direction?</p> <p>22 <b>A In my reports?</b></p> <p>23 Q Yes.</p> <p>24 <b>A At paragraphs 174 through 177 of my opening</b></p> <p>25 <b>report.</b></p>	<p style="text-align: right;">Page 517</p> <p>1 <b>A So LB-031 is saying that you exchange the</b></p> <p>2 <b>inter- -- interleaver delay in terms of octets, and</b></p> <p>3 <b>it's the end-to-end delay.</b></p> <p>4 <b>It says that that delay in octets has to be</b></p> <p>5 <b>enough to satisfy the smallest maximum delay at the</b></p> <p>6 <b>highest bit rate.</b></p> <p>7 <b>And then, if a -- if a transceiver uses more</b></p> <p>8 <b>memory -- has more memory available, it's free to use</b></p> <p>9 <b>it.</b></p> <p>10 <b>And then the smaller of the two are selected</b></p> <p>11 <b>in -- in both directions.</b></p> <p>12 <b>So the --</b></p> <p>13 Q I'm sorry. I'm sorry. Let me stop you</p> <p>14 there.</p> <p>15 You said it's free to use it. I -- I think</p> <p>16 you misspoke; correct?</p> <p>17 It's -- it's free to tell the other side</p> <p>18 about it; right?</p> <p>19 <b>A It's free to tell the other side about it,</b></p> <p>20 <b>and it's free to use it.</b></p> <p>21 Q How so?</p> <p>22 <b>A You can always use more memory for</b></p> <p>23 <b>interleaving and de-interleaving than the minimum.</b></p> <p>24 Q But it's not free to use more octets of</p> <p>25 delay; correct?</p>
<p style="text-align: right;">Page 516</p> <p>1 Q And that's Exhibit 23; right?</p> <p>2 <b>A Yes.</b></p> <p>3 Q I'm sorry.</p> <p>4 You said paragraphs 174 --</p> <p>5 <b>A Right.</b></p> <p>6 Q -- through 177?</p> <p>7 <b>A Sorry. Page 65.</b></p> <p>8 Q No, that's okay.</p> <p>9 Okay. So I'm looking at paragraph 175. 175</p> <p>10 is just a repeat of the paragraph at the bottom of</p> <p>11 page 3. I mean, it's literally a quote from the</p> <p>12 bottom of page 3 of the LB-031 reference, which says:</p> <p>13 "The VTU-0 and VTU-R would then select the</p> <p>14 smaller of the transmitter and receiver capabilities</p> <p>15 in each direction as the end-to-end capabilities."</p> <p>16 Do you see that?</p> <p>17 <b>A Yes.</b></p> <p>18 Q Okay. So that's consistent with</p> <p>19 Dr. Cooklev's view of LB-031.</p> <p>20 Can you tell me where else you have described</p> <p>21 anything that is different than the -- the idea that</p> <p>22 in LB-031, it's contemplated that each device can then</p> <p>23 use independently in each direction up to the amount</p> <p>24 that they agree on as -- as the smallest capability of</p> <p>25 each device in each direction?</p>	<p style="text-align: right;">Page 518</p> <p>1 <b>A Correct.</b></p> <p>2 Q Okay. So whatever amount of memory is</p> <p>3 required to implement its octets of delay, to</p> <p>4 implement its interleaver or de-interleaver, it can't</p> <p>5 use more than that; right?</p> <p>6 <b>A It can't use more -- it can't impose more</b></p> <p>7 <b>delay than that.</b></p> <p>8 Q Okay. So if -- and let's -- let's -- let's</p> <p>9 try to simplify the discussion. Let's -- let's talk</p> <p>10 about just a single direction. Let's talk about the</p> <p>11 downstream direction. So I'm going to try to limit my</p> <p>12 questions to the downstream direction.</p> <p>13 So if the VTU-R says that I can support up to</p> <p>14 8 kilobytes of delay downstream, and the VTU-0 says</p> <p>15 that it can support up to 12 kilobytes of delay</p> <p>16 downstream, what would they then select as the -- the</p> <p>17 amount of delay downstream that either device could</p> <p>18 choose to use?</p> <p>19 <b>A According to LB-031, it would be the smaller.</b></p> <p>20 <b>So it would be the 8 kilobytes.</b></p> <p>21 Q Okay. And so is there -- so given LB-031, is</p> <p>22 there any scenario under which -- again, a teaching in</p> <p>23 LB-031 that I'm going to ask you to point me to, that</p> <p>24 either device could attempt to use more than</p> <p>25 8 kilobytes of delay in the downstream direction?</p>

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<p style="text-align: right;">Page 519</p> <p>1       <b>A No.</b></p> <p>2       <b>Q</b> Okay. So for example, the additional</p> <p>3       4 kilobytes of delay that the VTU-0 was capable of</p> <p>4       using, those will never be used in the downstream</p> <p>5       direction between those two devices; correct?</p> <p>6       <b>A Are you talking memory or delay?</b></p> <p>7       <b>Q</b> Delay.</p> <p>8       <b>A If the delay is set to 8 kilobytes, then</b></p> <p>9       <b>that's the delay that the two ends would achieve.</b></p> <p>10       <b>Q</b> Okay. Now, let me add to that scenario. So</p> <p>11       you've got the VTU-0 saying that I can support</p> <p>12       12 kilobytes of delay downstream. The VTU-R is saying</p> <p>13       it can support up to 8 kilobytes downstream.</p> <p>14       Now, I'm going to let -- I'm going to add</p> <p>15       upstream to that. So the VTU-R -- I'm sorry -- the</p> <p>16       VTU-0 says that it can support -- just to keep this</p> <p>17       simple, it can support 8 upstream. The VTU-R says, I</p> <p>18       can support 12 kilobytes upstream.</p> <p>19       What is the max amount of delay that those</p> <p>20       devices could implement in the upstream direction,</p> <p>21       given the teaching of LB-031?</p> <p>22       <b>A Can you repeat your numbers?</b></p> <p>23       <b>Q</b> Yes. I'm sorry. I kept downstream the same.</p> <p>24       So VTU-0 is 12 downstream. VTU-R is 8 downstream.</p> <p>25       Now upstream, VTU-0 is 8, so I'm flipping it, and</p>	<p style="text-align: right;">Page 521</p> <p>1       let me just ask the question. I don't recall exactly</p> <p>2       what you said.</p> <p>3       But -- so if you'd take a look at the bottom</p> <p>4       of column 6, the paragraph that begins at about</p> <p>5       line 21. There's a sentence that says, quote -- and</p> <p>6       the sentence begins at about line 55. It says:</p> <p>7       "When the modem is installed at the end of</p> <p>8       the line, and depending on the service actually</p> <p>9       provided by the operator, the control means MCD may</p> <p>10       retrieve the corresponding values of I, M, I prime,</p> <p>11       and M prime from the stored table."</p> <p>12       Do you see that?</p> <p>13       <b>A I do.</b></p> <p>14       <b>Q</b> So do you have an understanding anything,</p> <p>15       other than that, at the time of installation, one of</p> <p>16       the 12 services is then selected and paired with a</p> <p>17       modem at the central office side that is also</p> <p>18       configured for that service?</p> <p>19       <b>A I don't understand the -- I don't understand</b></p> <p>20       <b>this to be disclosing that the -- that one of the</b></p> <p>21       <b>12 services is selected at installation and never</b></p> <p>22       <b>changed.</b></p> <p>23       <b>Q</b> Okay. And what disclosure of Mazzoni do you</p> <p>24       rely on for that?</p> <p>25       <b>A Well, in describing the partitioning of the</b></p>
<p style="text-align: right;">Page 520</p> <p>1       VTU-R is 12 upstream.</p> <p>2       <b>A Okay.</b></p> <p>3       <b>Q</b> What -- what is the maximum number of bytes</p> <p>4       of delay that those devices could implement upstream,</p> <p>5       given the messaging scheme of LB-031?</p> <p>6       <b>A 8 kilobytes.</b></p> <p>7       <b>Q</b> Okay. So for example, they couldn't decide</p> <p>8       that they're going to all of a sudden use 12 kilobytes</p> <p>9       upstream because the VTU-0 is going to borrow the 4</p> <p>10       that it didn't use downstream, and add it to the</p> <p>11       upstream path; right?</p> <p>12       <b>A Well, I would expect that, if the VTU-0 could</b></p> <p>13       <b>do that, it would -- it would have indicated a larger</b></p> <p>14       <b>number for upstream.</b></p> <p>15       <b>Q</b> Okay. But then we're back in the Mazzoni</p> <p>16       problem; right?</p> <p>17       Because if it -- because if it -- it only has</p> <p>18       a total of 20 kilobytes of memory, and it says -- it</p> <p>19       says 12 downstream and 12 upstream, then we've got a</p> <p>20       problem; don't we?</p> <p>21       <b>A Yes.</b></p> <p>22       <b>Q</b> Okay. So let's go back to the Mazzoni</p> <p>23       reference.</p> <p>24       <b>A (Witness complies.)</b></p> <p>25       <b>Q</b> So you -- you had said something about -- and</p>	<p style="text-align: right;">Page 522</p> <p>1       <b>memory between the interleaver and the de-interleaver</b></p> <p>2       <b>at the bottom of column 5, it talks about an</b></p> <p>3       <b>asymmetrical service, and it talks about the memory</b></p> <p>4       <b>space is then divided into a first memory space</b></p> <p>5       <b>assigned to the interleaving means, and a second</b></p> <p>6       <b>memory space assigned to the de-interleaving means,</b></p> <p>7       <b>which to me suggests that's happening at -- at run</b></p> <p>8       <b>time.</b></p> <p>9       <b>Q</b> Okay. Let me stop you there.</p> <p>10       But at run time, couldn't it just be as</p> <p>11       simple as it's taken the I, M, I and M prime values</p> <p>12       that were retrieved for the service installed at the</p> <p>13       time of installation, and simply using them to</p> <p>14       implement the interleaver/de-interleaver?</p> <p>15       <b>A It's possible. That would be a very</b></p> <p>16       <b>restrictive -- that would be a really restrictive</b></p> <p>17       <b>system.</b></p> <p>18       <b>Q</b> Okay. But again, I'm trying to understand.</p> <p>19       Given Mazzoni's disclosure -- so you've pointed out,</p> <p>20       it would be restrictive.</p> <p>21       But you haven't pointed out anything, at</p> <p>22       least not there, that necessarily means that it's</p> <p>23       doing something other than pulling I, M, I prime, and</p> <p>24       M prime, at the time of installation; right?</p> <p>25       <b>A Well, at column 4, line 15, it refers to</b></p>

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1 installing the device, which is then capable of  
2 processing all of the different services.

3 Q Okay. Right.

4 So you can install a de- -- you can -- you  
5 can create a device; right?

6 So you create your Mazzoni CPE device, and it  
7 has 27,000K of memory to support the various services.

8 But then you take that box to the customer's home, and  
9 through some sort of interface to the device, you say,  
10 This guy gets the A3 service. It's installed.

11 A3 service is up and running.

12 Is that inconsistent with anything you just  
13 read there?

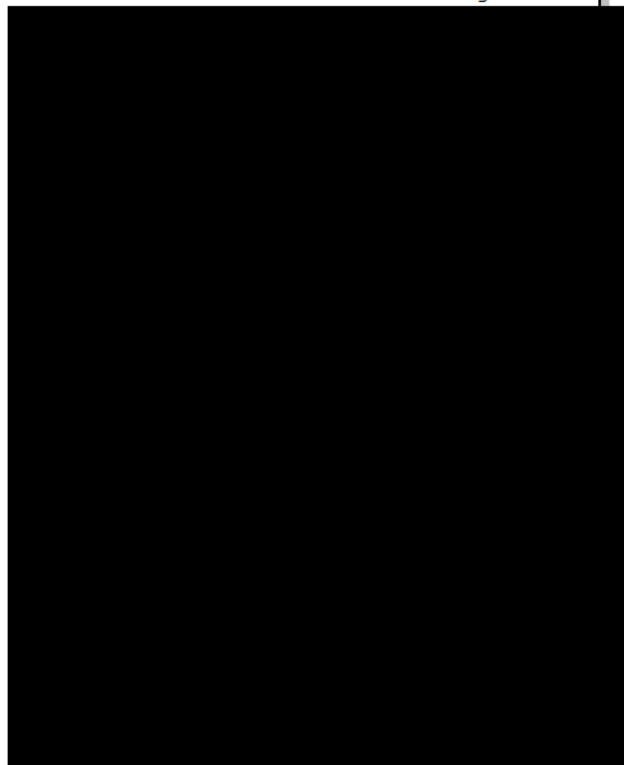
14 A Well, it's somewhat inconsistent with the  
15 last sentence of that paragraph, which says the  
16 parameters of the memory space of that memory may need  
17 to be set in accordance with the service actually  
18 processed by the device.

19 Q Okay. So the A3 service is actually being  
20 processed by that device; right?

21 In that scenario, where I've installed the  
22 box, and I've set the A3 service, so then the memory  
23 space was set in accordance with the service actually  
24 processed by the device; right?

25 A That would be one very limiting way to deploy

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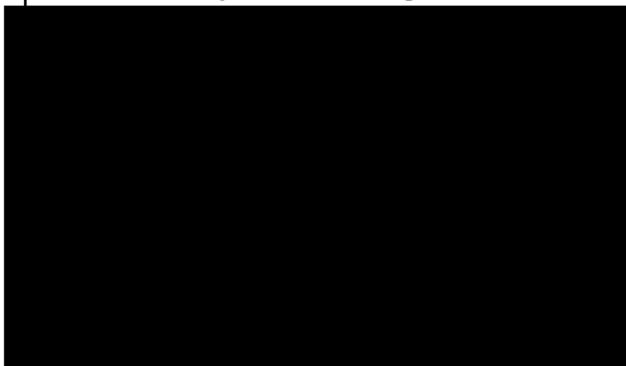
1 VDSL service.

2 Q Well, in fact, I think your comment about  
3 Mazzoni overall is that it is limiting; right?

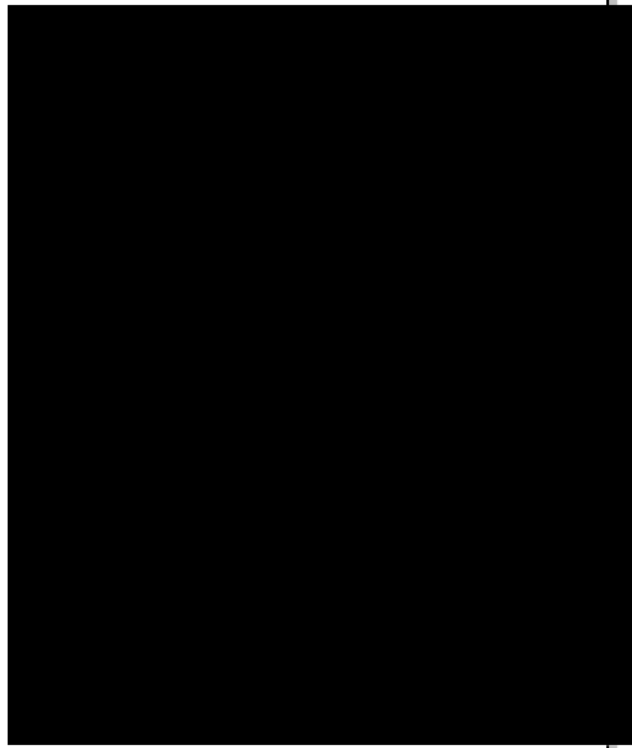
4 A It has a number of aspects that are limiting.  
5 It's -- it's got a lot of flexibility in some ways,  
6 but for example, that table is limiting.

7 Q Okay. So one of the -- one of the things  
8 that, you know, someone may view as a downside of  
9 Mazzoni, which is that he has 12 pre-configured  
10 services. Someone else may view that as a benefit,  
11 though; right?

12 A I don't know. I don't know how people would  
13 necessarily view it. It's -- it's possible.



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<p style="text-align: right;">Page 527</p> <div style="background-color: black; width: 100%; height: 50px; margin-bottom: 10px;"></div> <p>5 Q Okay. So I think we've agreed that the I and</p> <p>6 M and I prime and M prime parameters are not</p> <p>7 exchanged -- well, let me go more basic than that.</p> <p>8 Mazzoni itself does not describe any</p> <p>9 messaging scheme, for initialization or otherwise, to</p> <p>10 set up any of its transmission parameters; correct?</p> <p>11 <b>A It does not appear to contemplate things like</b></p> <p>12 <b>initialization.</b></p> <p>13 Q Okay. So earlier, when we were talking about</p> <p>14 the amount of memory that Mazzoni calculates for use</p> <p>15 by its interleaver and de-interleaver -- let me ask</p> <p>16 you more directly.</p> <p>17 So do you have an opinion, one way or the</p> <p>18 other, whether Mazzoni's bit rates, that are provided</p> <p>19 for each service, are actually variable, as opposed to</p> <p>20 being precisely the bit rate that the service is</p> <p>21 indicated for?</p> <p>22 <b>A I'm not sure I understand your question.</b></p> <p>23 Q Okay. So let me -- so let me -- let me use</p> <p>24 an example here.</p> <p>25 So let's take a look at the -- let's talk</p>	<p style="text-align: right;">Page 529</p> <p>1 <b>both of those paths are present, which he, I believe,</b></p> <p>2 <b>contemplates.</b></p> <p>3 <b>No. I'm thinking of a different reference.</b></p> <p>4 <b>So yes, that would be my understanding, is</b></p> <p>5 <b>that that would be the line rate.</b></p> <p>6 Q Okay. So the -- so 362 times 64 kilobits per</p> <p>7 second is -- is precisely the line rate that will be</p> <p>8 delivered with the S6 service; correct?</p> <p>9 <b>A I don't have any reason to think that's not</b></p> <p>10 <b>correct.</b></p> <p>11 Q Okay. And there's no -- there's no</p> <p>12 negotiation where you might arrive at a lower bit rate</p> <p>13 or a higher bit rate; correct?</p> <p>14 <b>A Disclosed explicitly in here?</b></p> <p>15 Q Correct.</p> <p>16 <b>A I don't see anything.</b></p> <p>17 Q So there's no disclosure that, depending on</p> <p>18 the bit rate, that theoretically it might achieve</p> <p>19 that's something different than this number, we're</p> <p>20 then going to go off and adjust our I and M; right?</p> <p>21 <b>A Well, if the -- I think that the way that a</b></p> <p>22 <b>person having ordinary skill would read this would be,</b></p> <p>23 <b>if you signed up for or were allocated the S6 service,</b></p> <p>24 <b>and the line conditions were such that it couldn't be</b></p> <p>25 <b>supported, maybe it would drop back to S5, as an</b></p>
<p style="text-align: right;">Page 528</p> <p>1 about the -- so at the top of column 4 of Mazzoni, in</p> <p>2 line 1, there's -- this is picking up in the middle of</p> <p>3 the sentence. It says:</p> <p>4 "In the fastest symmetrical service, S6 has a</p> <p>5 bit rate of 362 times 64 kilobits per second."</p> <p>6 Do you see that?</p> <p>7 <b>A I do.</b></p> <p>8 Q Okay. So when Mazzoni provides the S6</p> <p>9 service, is it your understanding that it will be</p> <p>10 providing exactly 362 times 64 kilobits per second?</p> <p>11 <b>A It's not clear to me whether that's the line</b></p> <p>12 <b>data rate or the user data rate.</b></p> <p>13 Q But if it's being used to determine the size</p> <p>14 of an interleaver/de-interleaver memory, wouldn't you</p> <p>15 conclude that it's the line data rate?</p> <p>16 <b>A Yes, I would.</b></p> <p>17 Q Okay. Because after all, bits and bytes to</p> <p>18 an interleaver and de-interleaver, they don't</p> <p>19 distinguish between user data and other sorts of</p> <p>20 overhead, for example; right?</p> <p>21 <b>A Right.</b></p> <p>22 <b>But -- but let me actually revise my answer.</b></p> <p>23 <b>This -- it's not clear that that's the -- the</b></p> <p>24 <b>bit rate of the interleaved path or fast and</b></p> <p>25 <b>interleaved, assuming that they're -- that they --</b></p>	<p style="text-align: right;">Page 530</p> <p>1 <b>example.</b></p> <p>2 Q And if it dropped back to S5, it would then</p> <p>3 pull the I and M again out of the table that it</p> <p>4 stores; right?</p> <p>5 <b>A That's correct.</b></p> <p>6 Q Okay. But that fallback operation is not</p> <p>7 disclosed in any of them; right?</p> <p>8 <b>A It's not explicitly disclosed. I think it's</b></p> <p>9 <b>clear that it -- it -- it would be possible.</b></p> <p>10 Q Do you know how many -- we were talking about</p> <p>11 the AT&amp;T service profiles. Do you know how many</p> <p>12 single line VDSL2 service profiles AT&amp;T provides?</p> <p>13 <b>A I don't know. I'd have to look at the</b></p> <p>14 <b>document.</b></p> <p>15 MR. MCANDREWS: Okay. It seems like a good</p> <p>16 time for a break.</p> <p>17 THE VIDEOGRAPHER: Going off the record. The</p> <p>18 time is now 12:28.</p> <p>19 (Lunch break taken at 12:28 p.m.)</p> <p>20 ---oOo---</p> <p>21</p> <p>22</p> <p>23</p> <p>24</p> <p>25</p>

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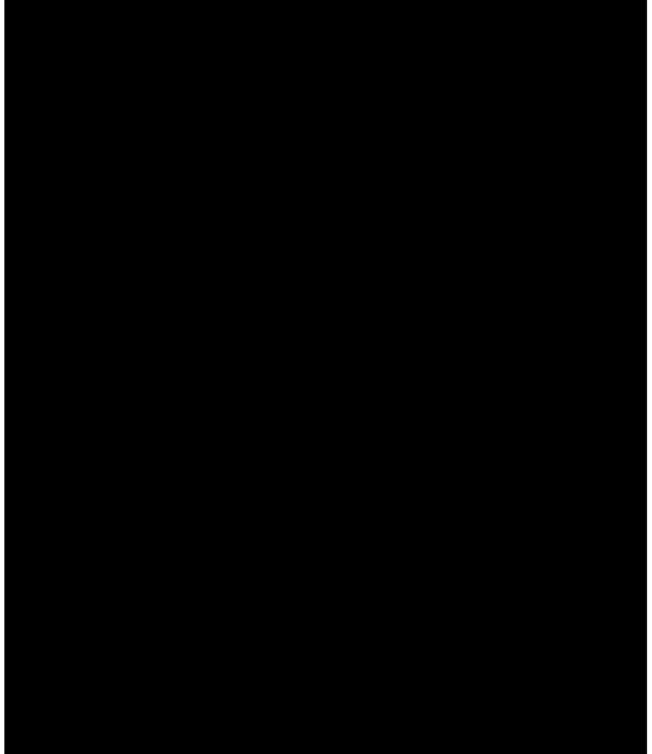
<p style="text-align: right;">Page 531</p> <p>1 AFTERNOON SESSION</p> <p>2 1:36 P.M.</p> <p>3</p> <p>4</p> <p>5</p> <p>6 THE VIDEOGRAPHER: Going on the record. The</p> <p>7 time is now 1:36.</p> <p>8 MR. MCANDREWS: This morning, we briefly</p> <p>9 talked about your preparation for the deposition and</p> <p>10 the materials that you considered in preparing for the</p> <p>11 deposition and in preparing your reports.</p> <p>12 Q Is it correct that you did not talk to -- is</p> <p>13 it Dr. Walker?</p> <p>14 A I don't know --</p> <p>15 Q Okay.</p> <p>16 A -- actually.</p> <p>17 Q I'll call him Dr. Walker.</p> <p>18 So -- so Dr. Walker -- is it true that you</p> <p>19 did not speak to him in preparing for your deposition</p> <p>20 today?</p> <p>21 A I -- I -- I met him yesterday for the first</p> <p>22 time, but it was in passing, and I didn't talk to him</p> <p>23 about my -- I did -- I didn't -- it was social</p> <p>24 introductions. Nice to meet you.</p> <p>25 And I don't -- I talked to him once in the</p>	<p style="text-align: right;">Page 533</p> <p>1 report, like, final and signed?</p> <p>2 A I think so.</p> <p>3 Q Do you know whether it was his first report</p> <p>4 on the issue of infringement for Family 3?</p> <p>5 First of all, let me ask you: Was it on the</p> <p>6 issue of Family 3 infringement?</p> <p>7 A Yes, I believe so.</p> <p>8 Q Okay. Was there a single report, or were</p> <p>9 there multiple?</p> <p>10 A I -- I saw a report a while back, and then I</p> <p>11 saw, I believe, a final version of another report</p> <p>12 either Monday or yesterday.</p> <p>13 Q You're saying "another report."</p> <p>14 A second report?</p> <p>15 A I think it was a second report. It was the</p> <p>16 final version, as far as I understand.</p> <p>17 Q The final version of a second report of</p> <p>18 Dr. Walker?</p> <p>19 A I think so. I didn't -- I didn't compare it</p> <p>20 to the first report that I saw, or the -- what I had</p> <p>21 reviewed before.</p> <p>22 Q Did you intend to supplement your expert</p> <p>23 report on Family 3 infringement, based on what you saw</p> <p>24 in the last couple of days?</p> <p>25 A No.</p>
<p style="text-align: right;">Page 532</p> <p>1 course of preparing my reports, but I don't remember</p> <p>2 which family it was connected with.</p> <p>3 Q Okay. But since the time that you submitted</p> <p>4 your last report for Family 3, have you spoken to</p> <p>5 Dr. Walker substantively about anything relating to</p> <p>6 Family 3?</p> <p>7 A I have not spoken to him about anything</p> <p>8 directly related to Family 3.</p> <p>9 Q Okay. Have you received any additional</p> <p>10 written materials from Dr. Walker relating to</p> <p>11 Family 3 since that time?</p> <p>12 A Just his reports.</p> <p>13 Q Just the reports that you understand to have</p> <p>14 been submitted on the same dates as your reports?</p> <p>15 A That's my understanding. I don't know how</p> <p>16 many reports he submitted. I believe that I saw all</p> <p>17 of them.</p> <p>18 Q Okay. So for example, if there was a report</p> <p>19 regarding Family 3 that was first, I guess, issued</p> <p>20 today and provided to us today, have you seen that</p> <p>21 report?</p> <p>22 A I don't know the dates of the reports that</p> <p>23 I've seen. I did review a report of Dr. Walker's</p> <p>24 Monday or yesterday. I don't remember.</p> <p>25 Q And did you understand it to be a complete</p>	<p style="text-align: right;">Page 534</p> <p>1 Q Do any of your opinions today, your</p> <p>2 testimony, rely on that report?</p> <p>3 A No.</p> <p>4 Q Did you spend any time reading that report?</p> <p>5 A I read it either Monday or -- I think Monday</p> <p>6 I read it.</p> <p>7 Q And you understood it to be in final form on</p> <p>8 Monday?</p> <p>9 A Yes.</p> <p>10 Q Was that a topic of discussion with your</p> <p>11 attorneys on Monday?</p> <p>12 A I don't think we discussed it, no.</p> <p>13 Q Where did you get it from?</p> <p>14 A From Goodwin.</p> <p>15 Q You got it during the course of the meeting</p> <p>16 on Monday?</p> <p>17 A I believe I got it after the meeting.</p> <p>18 Q And what were you told about what that</p> <p>19 document was?</p> <p>20 A I believe the e-mail said it was a final</p> <p>21 version of the report.</p> <p>22 Q And you were asked to read it?</p> <p>23 A No. It was for information.</p> <p>24 Q Okay. Did you have an understanding that</p> <p>25 that document would be provided to our law firm?</p>

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1       **A** I assume so. I -- I don't -- I -- I didn't  
2       **think about that.**  
3       **Q** If it was final on Monday, do you know why it  
4       wasn't provided to us until today?  
5       **A** I don't know.  
6       **Q** Do you have an understanding that there was a  
7       second Walker report related to Family 2?  
8       **A** I don't know. I don't have any recollection  
9       of that.  
10      **Q** Did you re- -- on Monday, did you review any  
11      Family 2 reports of Walker?  
12      **A** I don't believe so.  
13      **Q** Did you review any Family 2 reports of Walker  
14      in preparing for your Family 2 deposition?  
15      **A** I don't -- I -- I -- I did. His -- I believe  
16      his rebuttal report to Dr. Almeroth.  
17      **Q** Okay. And did you understand there to be a  
18      second report of Dr. Walker directed to Family 2  
19      infringement?  
20      **A** I am not aware of that.  
21      **Q** And so, if you've seen one, you don't recall  
22      having seen one?  
23      **A** That's correct. I don't recall having seen  
24      more than one Family 2 report.  
25      **Q** Okay. And can you recall what issues the

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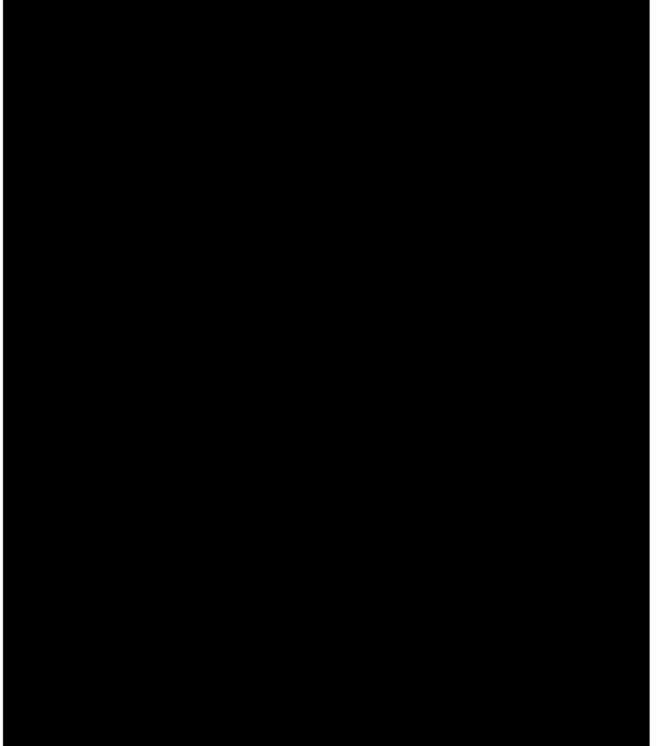


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1       Family 3 report -- the new Family 3 report of  
2       Dr. Walker addresses?  
3       **A** I believe he was responding to Dr. Almeroth's  
4       reply.  
5       **Q** Okay. And is there any information in that  
6       report that's relevant to your testimony today?  
7       **A** It's relevant in that it addresses  
8       Dr. Almeroth's infringement position.  
9       **Q** Okay. Is there anything in particular about  
10      his infringement position that you recall being  
11      addressed in the Walker report?  
12      **A** I don't remember anything in particular.



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32 (Pages 539 to 542)



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4 Q Okay. And so we just talked about the shared  
5 memory element of the claim. I want to talk about an  
6 element that shows up only in the '473 patent of  
7 Family 3.

8 And again, if you could refer back to  
9 page 55. It's in front of you there.

10 A (Witness complies.)

11 Q And it's -- one, two, three, four, five --  
12 it's the sixth term down in the left-hand column. It  
13 says:

14 "Wherein at least a portion of the memory may  
15 be allocated to the interleaving function or the  
16 de-interleaving function at any one time, depending on  
17 the message."

18 And I -- I truncated there. I know that  
19 there is more language at issue. But I think that  
20 language actually shows up in a patent that's not at  
21 stake in the 2Wire case. So I was reading that  
22 without some of the stuff in brackets.

23 So let me just state it again. The language  
24 is:

25 "Wherein at least a portion of the memory may

33 (Pages 543 to 546)



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<p style="text-align: right;">Page 547</p> <p>1 be allocated to the interleaving function or the</p> <p>2 de-interleaving function at any one particular time,</p> <p>3 depending on the message."</p> <p>4 Do you see that?</p> <p>5 A I do.</p> <p>6 Q And so let me break that down. Let -- let --</p> <p>7 let me leave out the "depending on the message" part,</p> <p>8 for starters.</p> <p>9 A Okay.</p> <p>10 Q So what we just described, where the --</p> <p>11 the -- the last memory location for an interleaver is</p> <p>12 then followed one position later by the first location</p> <p>13 for the de-interleaver, and that boundary can move,</p> <p>14 depending on the size of the interleaver, would you</p> <p>15 agree with me that that meets the language of this</p> <p>16 claim element, setting aside for the moment the</p> <p>17 "depending on the message"?</p> <p>18 A Well, the -- the -- the words "may be</p> <p>19 allocated" would certainly seem to cover that type of</p> <p>20 scenario.</p> <p>21 Q Okay. And if -- and if the message includes</p> <p>22 I and D values, so for example, if the message</p> <p>23 includes the I value and the D value for the</p> <p>24 interleaver -- for the upstream interleaver, for</p> <p>25 example, in the Accused Products, then whether a</p>	<p style="text-align: right;">Page 549</p> <div style="background-color: black; width: 100%; height: 150px; margin-bottom: 10px;"></div> <p>16 Q So could you -- I think you still have</p> <p>17 Exhibit 29 in front of you. It's the LB-031</p> <p>18 reference.</p> <p>19 A (Witness complies.)</p> <p>20 Q So do you understand that Dr. Cooklev's</p> <p>21 position is that the LB-031 disclosure is</p> <p>22 inconsistent?</p> <p>23 In other words, it could not be used with a</p> <p>24 device that implements shared memory?</p> <p>25 A I understand that to be his position.</p>
<p style="text-align: right;">Page 548</p> <p>1 portion of the memory is allocated to the interleaver</p> <p>2 or de-interleaver, would depend on the message; isn't</p> <p>3 that right?</p> <p>4 A Did you say the amount allocated would depend</p> <p>5 on the values or on the message?</p> <p>6 Q No.</p> <p>7 The -- I said whether a particular byte of</p> <p>8 memory is used -- I'm sorry -- whether a particular</p> <p>9 byte of memory is allocated to the interleaver</p> <p>10 function, or to the de-interleaver function would</p> <p>11 depend on the I and D provided in the OPMS message; is</p> <p>12 that right?</p> <p>13 A Well, I think it would depend on how it was</p> <p>14 implemented.</p> <p>15 Q But assuming that all of the memory that was</p> <p>16 allocated to the interleaving function was in the</p> <p>17 memory addresses that come first, and then all of the</p> <p>18 memory that is allocated to the de-interleaver</p> <p>19 function starts one byte later, then whether a</p> <p>20 particular portion of the memory is allocated to the</p> <p>21 interleaver function, or the de-interleaver function,</p> <p>22 would depend on the message; right?</p> <p>23 A It would depend on the values of I and D for</p> <p>24 the interleaver and the -- for the de-interleaver, and</p> <p>25 again, also on the implementation.</p>	<p style="text-align: right;">Page 550</p> <p>1 Q Do you disagree with that?</p> <p>2 A I do.</p> <p>3 Q Okay.</p> <p>4 A Yes.</p> <p>5 Q Okay. So you disagree with that. Might come</p> <p>6 back to that in a moment.</p> <p>7 But let me ask you this: Do you believe that</p> <p>8 the LB-031 reference discloses the use of shared</p> <p>9 memory?</p> <p>10 A I believe that I stated in my reports that I</p> <p>11 don't think it's explicitly disclosed, but that a</p> <p>12 person having ordinary skill in the art would</p> <p>13 recognize that the disclosures could be used with a</p> <p>14 shared memory approach.</p> <p>15 Q Okay. So your -- your position is that it</p> <p>16 could be used.</p> <p>17 But given the disclosure of LB-031, is it</p> <p>18 necessarily the case that it could only be used with a</p> <p>19 device that implements shared memory?</p> <p>20 A I don't think the disclosure of LB-031 is</p> <p>21 limited to use with a shared memory.</p> <p>22 Q Okay. So I'm going to give you a couple of</p> <p>23 other exhibits here, so...</p> <p>24 (Document marked Exhibit 30</p> <p>25 for identification.)</p>

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<p style="text-align: right;">Page 551</p> <p>1 MR. MCANDREWS: We've marked as Exhibit 30</p> <p>2 ITU G.993.1.</p> <p>3 (Document marked Exhibit 31</p> <p>4 for identification.)</p> <p>5 MR. MCANDREWS: We've marked as Exhibit 31</p> <p>6 ITU G.992.2.</p> <p>7 (Document marked Exhibit 32</p> <p>8 for identification.)</p> <p>9 MR. MCANDREWS: Exhibit 32 is U.S. Patent</p> <p>10 No. 5,751,741, naming as the first inventor Voith.</p> <p>11 (Document marked Exhibit 33</p> <p>12 for identification.)</p> <p>13 MR. MCANDREWS: And Exhibit 33 is U.S. Patent</p> <p>14 No. 6,707,822, naming Fadavi-Ardekani as the first</p> <p>15 named inventor. And that's F-A-D-A-V-I, hyphen,</p> <p>16 A-R-D-E-K-A-N-I.</p> <p>17 Q So I'm -- I'm going to ask you a similar</p> <p>18 question to what I just asked you. So I'm going to go</p> <p>19 down the list here.</p> <p>20 So the 993.1 ITU specification -- first of</p> <p>21 all, do you recognize Exhibit 30?</p> <p>22 A I do.</p> <p>23 Q And Exhibit 30 is -- is the ITU G.993.1</p> <p>24 standard or recommendation that you rely on as prior</p> <p>25 art, with respect to the Family 3 patents; is that</p>	<p style="text-align: right;">Page 553</p> <p>1 A That's correct.</p> <p>2 Q Okay. Does G.992.2 disclose shared memory?</p> <p>3 A Well, similarly to 993.1, the use of shared</p> <p>4 memory are not -- is an implementation decision, and</p> <p>5 is not something that a standard would necessarily</p> <p>6 specify.</p> <p>7 So it -- similarly to G.993.1, my opinion is</p> <p>8 that it doesn't exclude the use of shared memory, but</p> <p>9 it -- it -- yeah, it doesn't exclude the use of shared</p> <p>10 memory.</p> <p>11 Q Okay. But you would agree, that the</p> <p>12 disclosure in 992.2 is consistent as well with the</p> <p>13 possible use of dedicated memory, where a certain</p> <p>14 amount of memory is dedicated only to an interleaver,</p> <p>15 and a certain amount of memory is dedicated only to a</p> <p>16 de-interleaver?</p> <p>17 A It does not describe or mandate any</p> <p>18 particular implementation, whether using dedicated</p> <p>19 memories or shared memory.</p> <p>20 Q So it could be used with dedicated memories?</p> <p>21 A It could be used with dedicated or shared.</p> <p>22 Q Okay. Now, I want you to take a look at the</p> <p>23 Voith reference that you have in front of you there,</p> <p>24 Exhibit 32.</p> <p>25 A (Witness complies.)</p>
<p style="text-align: right;">Page 552</p> <p>1 right?</p> <p>2 A It appears to be, yes.</p> <p>3 Q Okay. G.993.1, do you believe that that</p> <p>4 discloses the use of shared memory?</p> <p>5 A I don't believe it discloses it explicitly,</p> <p>6 but I don't believe it -- it would preclude the use of</p> <p>7 shared memory.</p> <p>8 Q Okay. So is it fair to say that it -- it</p> <p>9 doesn't require the use of shared memory, but it's</p> <p>10 your view that it could be used with shared memory?</p> <p>11 A It would not require the use of shared</p> <p>12 memory, but could be used with shared memory.</p> <p>13 Q Okay. And it could also be used with a</p> <p>14 device that has memory dedicated to an interleaver,</p> <p>15 and separate memory dedicated to a de-interleaver?</p> <p>16 A That's right.</p> <p>17 Q Okay. Exhibit 31, that you have in front of</p> <p>18 you there, is ITU-T G.992.2. I believe that sometimes</p> <p>19 that is referred to as the G.Lite standard; is that</p> <p>20 correct?</p> <p>21 A That's right.</p> <p>22 Q Okay. And Exhibit 31 is one of the prior art</p> <p>23 references that you rely on for your invalidity</p> <p>24 opinions, with respect to at least some of the Family</p> <p>25 3 patents; is that right?</p>	<p style="text-align: right;">Page 554</p> <p>1 Q And this -- so the Voith reference, that's</p> <p>2 one of the references you rely on as prior art for</p> <p>3 your invalidity positions, with respect to some of the</p> <p>4 Family 3 patents?</p> <p>5 A That's correct.</p> <p>6 Q Okay. When did you first learn about the</p> <p>7 Voith reference?</p> <p>8 A During the course of this litigation.</p> <p>9 Q Okay. Do you know either of the three named</p> <p>10 inventors?</p> <p>11 A Not to my knowledge.</p> <p>12 Q Okay. Do you recognize them as -- as</p> <p>13 individuals that participated in any DSL standards</p> <p>14 meetings?</p> <p>15 A I -- I don't recognize them specifically in</p> <p>16 that way. Motorola definitely participated, but I</p> <p>17 don't remember any of those three names as people that</p> <p>18 I ran across.</p> <p>19 Q Okay. So let's take a look at, for example,</p> <p>20 Figure 2 of the Voith reference.</p> <p>21 A (Witness complies.)</p> <p>22 Q And Figure 2 illustrates a box labeled 66</p> <p>23 that says "External Interleave/Deinterleave Memory."</p> <p>24 Do you see that?</p> <p>25 A I do.</p>

35 (Pages 551 to 554)

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<p style="text-align: right;">Page 555</p> <p>1 Q Is it your position that the Voith reference</p> <p>2 discloses shared memory in the way it was dis- --</p> <p>3 construed by the Court?</p> <p>4 <b>A I believe that a person having ordinary skill</b></p> <p>5 <b>would recognize that memory could be shared memory as</b></p> <p>6 <b>construed by the Court.</b></p> <p>7 Q So it could be.</p> <p>8 But is it also consistent with the Voith</p> <p>9 disclosure that the interleave/de-interleaver memory</p> <p>10 block 66 could include separate dedicated memory</p> <p>11 spaces for the interleaver and de-interleaver?</p> <p>12 <b>A It could be either dedicated or shared.</b></p> <p>13 Q And the Voith reference itself doesn't</p> <p>14 explicitly describe whether it is dedicated or shared;</p> <p>15 right?</p> <p>16 <b>A It does not say one way or the other.</b></p> <p>17 Q Okay. And the -- the last of the exhibits</p> <p>18 I've put in front of you there, Exhibit 33, which is</p> <p>19 U.S. Patent 6,707,822, first named inventor</p> <p>20 Fadavi-Ardekani.</p> <p>21 If I refer to this as the Fadavi reference,</p> <p>22 would you understand that to be the '822 patent?</p> <p>23 <b>A Yes.</b></p> <p>24 Q And the Fadavi reference is one of the items</p> <p>25 of prior art that you rely on in your invalidity</p>	<p style="text-align: right;">Page 557</p> <p>1 G.992.1?</p> <p>2 But I want to try to use the language he uses</p> <p>3 in this section, just to keep everything straight</p> <p>4 here; is that okay?</p> <p>5 <b>A Sure.</b></p> <p>6 <b>He could also be referring to T1.413 Issue 1</b></p> <p>7 <b>or Issue 2.</b></p> <p>8 <b>But I know what you mean when you say</b></p> <p>9 <b>standard ADSL versus G.Lite.</b></p> <p>10 Q Okay. So if we have -- so is it your</p> <p>11 understanding, of this disclosure, that the same --</p> <p>12 Well, let me ask you this: So do you</p> <p>13 understand what he means by an IDIM -- what Fadavi</p> <p>14 means by an IDIM?</p> <p>15 <b>A Yes.</b></p> <p>16 Q And what does that mean?</p> <p>17 <b>A It's the acronym he uses for the</b></p> <p>18 <b>interleave/de-interleave memory.</b></p> <p>19 Q Okay. So is your understanding of this</p> <p>20 section of Fadavi -- your understanding is that it's</p> <p>21 describing a single IDIM for a single device that can</p> <p>22 support both G.Lite and standard ADSL?</p> <p>23 <b>A Potentially.</b></p> <p>24 <b>He's first and foremost describing a device</b></p> <p>25 <b>for deployment in the central office, that can support</b></p>
<p style="text-align: right;">Page 556</p> <p>1 opinions, with respect to the Family 3 patents?</p> <p>2 <b>A That's correct.</b></p> <p>3 Q Okay. Do you believe that Fadavi-Ardekani</p> <p>4 discloses shared memory?</p> <p>5 <b>A I do.</b></p> <p>6 Q Can you tell me which aspects of Fadavi</p> <p>7 necessarily indicate that shared memory is being used?</p> <p>8 <b>A If you look at column 7, for example, he</b></p> <p>9 <b>calculates the amount of memory that would be required</b></p> <p>10 <b>for four G.Lite sessions running simultaneously.</b></p> <p>11 <b>He then relates that to a full rate ADSL</b></p> <p>12 <b>line, and I believe he uses the maximum interleave</b></p> <p>13 <b>depth and block size in that calculation.</b></p> <p>14 <b>And then he discusses using that same amount</b></p> <p>15 <b>of memory to support additional ADSL sessions, as long</b></p> <p>16 <b>as the interleave depth is lower.</b></p> <p>17 Q Okay. So let's -- let's break that down.</p> <p>18 So when you -- when you say "full rate ADSL,"</p> <p>19 are you referring to 992.1?</p> <p>20 <b>A At this state, yes.</b></p> <p>21 Q Okay. So -- and does Fadavi actually use</p> <p>22 full rate, or is he referencing that as standard ADSL?</p> <p>23 <b>A Right. He refers to it as standard ADSL.</b></p> <p>24 Q Okay. So is it okay that -- that when I say</p> <p>25 "standard ADSL," I know that we're talking about</p>	<p style="text-align: right;">Page 558</p> <p>1 <b>multiple DSL sessions all at the same time.</b></p> <p>2 Q Okay. So -- so are you saying that it's not</p> <p>3 clear whether he is proposing a single device with a</p> <p>4 single IDIM to support one or -- to support both in</p> <p>5 the same device?</p> <p>6 <b>A I don't think it excludes that.</b></p> <p>7 Q Okay. So why don't we -- so why don't we --</p> <p>8 since -- do you have an opinion on whether it does or</p> <p>9 it does not disclose that you're going to do all this</p> <p>10 in the same device?</p> <p>11 <b>A I think he discloses a very flexible device</b></p> <p>12 <b>that could be used in multiple ways, all standard --</b></p> <p>13 <b>what he called standard ADSL.</b></p> <p>14 <b>Is that what he calls it?</b></p> <p>15 Q Uh-huh.</p> <p>16 <b>A Versus G.Lite. He -- he talks about having</b></p> <p>17 <b>resources shared among different links, basically.</b></p> <p>18 Q Okay. So why don't we do it this way. Why</p> <p>19 don't we -- let's first talk about a G.Lite only</p> <p>20 version. Then we'll talk about a standard ADSL only</p> <p>21 version. And then -- and then we can talk about a</p> <p>22 device that is capable of doing both.</p> <p>23 <b>A Okay.</b></p> <p>24 Q So we cover it all; okay?</p> <p>25 So let's talk about a device -- and this is a</p>

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<p style="text-align: right;">Page 559</p> <p>1 CO device that can implement -- I guess that can</p> <p>2 support four G.Lite sessions.</p> <p>3 So can you tell me how much total</p> <p>4 interleaver/de-interleaver memory would be required to</p> <p>5 support four G.Lite sessions?</p> <p>6 <b>A Well, according to the patent, each</b></p> <p>7 <b>interleaver requires 4 kilobytes.</b></p> <p>8 <b>You said four; right?</b></p> <p>9 Q Yes.</p> <p>10 <b>A So that's 16 kilobytes for de-interleaving.</b></p> <p>11 <b>Well, actually, if it's in the CO, it's the</b></p> <p>12 <b>interleaver, but -- and then for upstream direction,</b></p> <p>13 <b>2 kilobytes per session, so that's another eight.</b></p> <p>14 <b>So he concludes that it's 24 kilobytes of RAM</b></p> <p>15 <b>for the four G.Lite sessions.</b></p> <p>16 Q Okay. So -- and is there -- is the fast path</p> <p>17 used in G.Lite?</p> <p>18 <b>A Yes. My recollect- -- I would -- I -- I</b></p> <p>19 <b>could look to see whether it's mandatory or optional,</b></p> <p>20 <b>but there -- there can be.</b></p> <p>21 Q So I don't know if this is what he's</p> <p>22 referring to. But on -- on about line 17, he says:</p> <p>23 "A fast path buffer is also required for fast</p> <p>24 path data in both the interleave and de-interleave</p> <p>25 processes, and requires 256 bytes of RAM per session,</p>	<p style="text-align: right;">Page 561</p> <p>1 (Recess taken.)</p> <p>2 THE VIDEOGRAPHER: Going on the record.</p> <p>3 This marks the beginning of Videotape No. 3,</p> <p>4 Volume III, in the deposition of Dr. Krista Jacobsen.</p> <p>5 The time is now 2:36.</p> <p>6 MR. MCANDREWS: Okay.</p> <p>7 Q Before the break, we were talking about</p> <p>8 G.Lite, and the memory requirements for implementing</p> <p>9 four sessions, and whether -- there was a question</p> <p>10 about whether G.Lite used a fast path and, therefore,</p> <p>11 needed to set aside a portion of the memory for fast</p> <p>12 path. And you were going to take a look at 992.2.</p> <p>13 What did you conclude?</p> <p>14 <b>A I concluded, there is only one latency path.</b></p> <p>15 <b>So it -- it's the interleaved path. So I would</b></p> <p>16 <b>conclude there is no need for this additional fast</b></p> <p>17 <b>path buffer in G.Lite.</b></p> <p>18 Q Okay. So -- and that's actually consistent</p> <p>19 with Fadavi at line -- starting at about line 12,</p> <p>20 where it says:</p> <p>21 "Therefore, 24 kilobytes of RAM is required</p> <p>22 to support four G.Lite sessions."</p> <p>23 Do you see that?</p> <p>24 <b>A I do see that.</b></p> <p>25 Q Okay. So using only the G.Lite example, is</p>
<p style="text-align: right;">Page 560</p> <p>1 or a total of 1 K bytes for four sessions."</p> <p>2 Is that referencing a G.Lite, or is that the</p> <p>3 standard ADSL?</p> <p>4 <b>A Well, it's definitely T1.413 Issue 1, because</b></p> <p>5 <b>there, you had to have fast and interleaved. Even if</b></p> <p>6 <b>you didn't necessarily have fast or interleaved data,</b></p> <p>7 <b>you had to have both paths.</b></p> <p>8 <b>Optionally, in 992.1 and T1.413 Issue 2, you</b></p> <p>9 <b>could have two paths. So it would apply to that.</b></p> <p>10 <b>And I would have to look to see if -- if</b></p> <p>11 <b>there were -- if dual latency was supported in 992.2.</b></p> <p>12 <b>Do you want me to look?</b></p> <p>13 Q Okay. Yeah, you can -- you can look.</p> <p>14 I -- actually, now that I read this, I think</p> <p>15 that might have been referring only to the standard</p> <p>16 ADSL.</p> <p>17 But why don't you look. Let's just...</p> <p>18 <b>A (Witness reading document.)</b></p> <p>19 MR. MCANDREWS: We're going to go off the</p> <p>20 record briefly while you read so we can change the</p> <p>21 disc. But you please go ahead and keep reading.</p> <p>22 THE VIDEOGRAPHER: This marks the end of</p> <p>23 Videotape No. 2, Volume III, in the deposition of</p> <p>24 Dr. Krista Jacobsen.</p> <p>25 The time is now 2:27. Going off the record.</p>	<p style="text-align: right;">Page 562</p> <p>1 it your position that the G.Lite example necessarily</p> <p>2 discloses the use of shared memory?</p> <p>3 <b>A I think it could use shared memory or another</b></p> <p>4 <b>implementation.</b></p> <p>5 Q So it could use shared memory, or it could</p> <p>6 use dedicated memory; correct?</p> <p>7 <b>A That would be another way to do it.</b></p> <p>8 Q Okay. So -- so four sessions, for example,</p> <p>9 implemented in a CO device, could have 16 kilobytes of</p> <p>10 downstream interleaver memory and 8 kilobytes of</p> <p>11 upstream de-interleaver memory, where the interleaver</p> <p>12 memory was only ever used for interleaving, and the</p> <p>13 de-interleaver memory was only ever used for</p> <p>14 de-interleaving; is that right?</p> <p>15 <b>A It could. It could also -- it could also</b></p> <p>16 <b>support, for example, fewer sessions than that where,</b></p> <p>17 <b>potentially, a portion of the memory would be used for</b></p> <p>18 <b>downstream in one configuration and upstream in the</b></p> <p>19 <b>other.</b></p> <p>20 Q Well, so let's -- let's explore that. So</p> <p>21 let's say, for example -- and I don't know if this is</p> <p>22 even possible. Let's just say hypothetically, you</p> <p>23 wanted to use that same amount of memory and support</p> <p>24 only two sessions; right?</p> <p>25 <b>A Okay.</b></p>

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<p style="text-align: right;">Page 563</p> <p>1 Q And you wanted to double your interleaver and</p> <p>2 de-interleaver depth for each session.</p> <p>3 A Okay.</p> <p>4 Q Does G -- G.Lite even allow that?</p> <p>5 A During the sessions?</p> <p>6 Q No. At a different time.</p> <p>7 A G.Lite describes different interleaver depth</p> <p>8 values that are possible.</p> <p>9 Q So -- so just to be clear, though, the -- the</p> <p>10 amounts that we just talked about there, those are the</p> <p>11 maximum that are necessary; right?</p> <p>12 A I believe so. At least according to</p> <p>13 Fadavi-Ardekani, a simple implementation requires</p> <p>14 4 kilobytes for downstream and 2 kilobytes for</p> <p>15 upstream.</p> <p>16 Q Okay. Well, let's just say theoretically</p> <p>17 that you could -- whether G.Lite is capable of doing</p> <p>18 it or not, let's say that you could -- instead of</p> <p>19 doing four G.Lite sessions, you decided to do</p> <p>20 two G.Lite sessions, and to double the size of your</p> <p>21 interleaver memory and double the size of your</p> <p>22 de-interleaver memory per session.</p> <p>23 A Okay.</p> <p>24 Q Okay. So -- and take the -- the dedicated</p> <p>25 example that I just described, where you've got</p>	<p style="text-align: right;">Page 565</p> <p>1 de-interleaving. You could do it that way.</p> <p>2 You could also, on a per-session basis, say,</p> <p>3 I need 6 kilobytes for downstream, 2 kilobytes for</p> <p>4 upstream. That would be another way.</p> <p>5 And then, when you changed the number of</p> <p>6 sessions, that would change where the memory was</p> <p>7 allocated for downstream and upstream.</p> <p>8 Q Okay. So -- so is that what you intended in</p> <p>9 your report when you -- when you -- you mentioned the</p> <p>10 sessions, and it wasn't clear to us what you meant by</p> <p>11 the sessions having anything to do with sharing.</p> <p>12 But is that what you intended --</p> <p>13 A That --</p> <p>14 Q -- in your report?</p> <p>15 A -- that's what I thought I said.</p> <p>16 Q Okay. I mean, you didn't -- you didn't</p> <p>17 provide any sort of illustration that showed how this</p> <p>18 would be divided up; did you?</p> <p>19 A No, I don't think I did.</p> <p>20 Q Okay. So let's go with that, though.</p> <p>21 So -- so you -- you intended to say that</p> <p>22 it -- that it -- that it could be divided up such</p> <p>23 that -- I guess you put session one -- everything you</p> <p>24 need for session one interleaver and de-interleaver in</p> <p>25 one spot. And then you put interleaver and</p>
<p style="text-align: right;">Page 564</p> <p>1 16 kilobytes of memory that are always used for the</p> <p>2 downstream interleaver, and 8 kilobytes that are</p> <p>3 always used for the upstream de-interleaver.</p> <p>4 So if you want to support two sessions rather</p> <p>5 than four, and double the size of your memories, isn't</p> <p>6 it possible that you would then just split up the 16</p> <p>7 between the two sessions?</p> <p>8 And so you have -- you have 8 kilobytes for</p> <p>9 session one downstream. You have 4 kilobytes for</p> <p>10 session one upstream. And then you have 8 kilobytes</p> <p>11 for session two downstream -- I'm sorry -- yeah,</p> <p>12 session two downstream, and 4 kilobytes for session</p> <p>13 two upstream.</p> <p>14 A That would be one way to do it.</p> <p>15 Q Okay. And Fadavi doesn't indicate that it</p> <p>16 would be done other than that way; correct?</p> <p>17 A Well, it doesn't say it would be done that</p> <p>18 way, either.</p> <p>19 I think a person reading -- a person having</p> <p>20 ordinary skill reading this, would understand if you</p> <p>21 had the four sessions, in -- in your example, you</p> <p>22 could lump all of the sessions -- well, you could</p> <p>23 arrange it in a number of ways.</p> <p>24 But you could say the first 16 kilobytes are</p> <p>25 for interleaving, and the last 8 kilobytes are for</p>	<p style="text-align: right;">Page 566</p> <p>1 de-interleaver in another spot, and so on.</p> <p>2 And then, when you make those memories larger</p> <p>3 because you're going to support a larger memory for</p> <p>4 fewer sessions, there would be some that -- there</p> <p>5 would be some memory portions that would be used by</p> <p>6 one thing at one time and another thing at a different</p> <p>7 time.</p> <p>8 Is that what you were saying?</p> <p>9 A That is it.</p> <p>10 Q Okay. But that's not necessarily the case;</p> <p>11 right?</p> <p>12 A It -- it doesn't explicitly say how it's</p> <p>13 done.</p> <p>14 The -- the point that I was making is, that</p> <p>15 you would understand reading this, that that would be</p> <p>16 one way to do it. The way that you mentioned might</p> <p>17 also be a way you could do it. It would be an</p> <p>18 implementation choice.</p> <p>19 Q And the particular implementation choice is</p> <p>20 not disclosed in Fadavi; correct?</p> <p>21 A I don't believe Fadavi describes where,</p> <p>22 within this IDIM, the interleaving part is taking</p> <p>23 place and the de-interleaving part is taking place.</p> <p>24 He describes that the -- the two portions are</p> <p>25 disjoint, but not how, from session to session, the</p>



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<p style="text-align: right;">Page 567</p> <p>1 different sessions are supported within that IDIM.</p> <p>2 Q Okay. So -- so you would agree with me that</p> <p>3 Fadavi does not necessarily disclose shared memory?</p> <p>4 A It doesn't disclose any particular</p> <p>5 implementation. My position is that it would be</p> <p>6 recognized as being implementable either in shared</p> <p>7 memory or dedicated memory.</p> <p>8 Q Okay. And I don't know if it's worth going</p> <p>9 through the standard ADSL version of this.</p> <p>10 But do you think we would arrive at the same</p> <p>11 place, where you would agree with me that it does not</p> <p>12 necessarily require the use of shared memory to</p> <p>13 implement four standard ADSL sessions?</p> <p>14 A It does not exclude that approach, but it</p> <p>15 does not explicitly require any particular</p> <p>16 implementation.</p> <p>17 Q Okay. So for example, would you agree with</p> <p>18 me that this is describing a total memory requirement</p> <p>19 of 76 kilobytes for four standard ADSL sessions?</p> <p>20 And this is beginning at about line 22 of</p> <p>21 column 7 of Fadavi.</p> <p>22 A I see that it does conclude that it would</p> <p>23 require 76 kilobytes for four standard ADSL sessions.</p> <p>24 Q Okay. And then after that, it says in</p> <p>25 parentheses:</p>	<p style="text-align: right;">Page 569</p> <p>1 memory location after that.</p> <p>2 In other words, not necessarily pooling all</p> <p>3 of the interleave memory together and all of the</p> <p>4 de-interleave memory together. You could do it either</p> <p>5 way.</p> <p>6 Q Okay. I need to ask that again, because I</p> <p>7 think you may have misspoke. I said -- I said, and</p> <p>8 that would not be inconsistent with Fadavi's</p> <p>9 disclosure; correct?</p> <p>10 And you said it would not be consistent.</p> <p>11 So let me -- let me rephrase the question.</p> <p>12 Let me start over here.</p> <p>13 So the -- the version of the division of</p> <p>14 memory that I went through, where you have 64 K of</p> <p>15 dedicated interleave memory, that you divide up</p> <p>16 amongst the four sessions, 8 K of dedicated</p> <p>17 de-interleaver memory that you divide up amongst the</p> <p>18 four sessions, and 4 K of fast path dedicated, that</p> <p>19 you divide up amongst the four sessions, that would</p> <p>20 not be inconsistent with Fadavi's disclosure; correct?</p> <p>21 A Well, it depends on how you're using</p> <p>22 "dedicated," because it's all in the same buffer.</p> <p>23 Are you saying dedicated means there is an</p> <p>24 immovable boundary between the part that's used for</p> <p>25 interleaving and the part that's used for</p>
<p style="text-align: right;">Page 568</p> <p>1 "64 K interleave plus 8 K de-interleave plus</p> <p>2 4 K fast path."</p> <p>3 Do you see that?</p> <p>4 A I do.</p> <p>5 Q Okay. So if I -- if I set up my block where</p> <p>6 I've got -- I've got 64 K consecutive memory addresses</p> <p>7 of interleave, so that's for the downstream, I've got</p> <p>8 8 K consecutive for the de-interleave upstream, and</p> <p>9 then I've got 4 K for the fast path, I could divide</p> <p>10 the 64 K up into four sessions for four separate</p> <p>11 downstream interleavers; right?</p> <p>12 A You could.</p> <p>13 Q And I could divide up the 8 K into</p> <p>14 four sessions of 2 K de-interleavers; right?</p> <p>15 A You could.</p> <p>16 Q And I could divide up the 4 K of fast path</p> <p>17 into 1 K for each session; right?</p> <p>18 A That would be one -- one way to do it.</p> <p>19 Q Okay. And that would not be inconsistent</p> <p>20 with Fadavi's disclosure; correct?</p> <p>21 A It would not be consistent.</p> <p>22 But in my opinion, it would be more</p> <p>23 cumbersome than simply doing what we talked about</p> <p>24 earlier, where interleave addresses from 0 to some</p> <p>25 number, and then de-interleave for that session one</p>	<p style="text-align: right;">Page 570</p> <p>1 de-interleaving?</p> <p>2 Q Yes.</p> <p>3 A Okay. That would be one way to implement</p> <p>4 this disclosure.</p> <p>5 And then the other -- another way would be,</p> <p>6 instead of doing that, you would set aside interleave</p> <p>7 memory for one session and de-interleave memory for</p> <p>8 that same session, and then do the same for the</p> <p>9 additional sessions.</p> <p>10 Q Okay. And I think your earlier answer that I</p> <p>11 wanted to clear up included a statement that, the way</p> <p>12 I described, would be more cumbersome; right?</p> <p>13 A In my opinion.</p> <p>14 Q Okay. Is that found anywhere in your written</p> <p>15 expert reports that it would be more cumbersome?</p> <p>16 A No. It's based on my understanding of</p> <p>17 Mazzoni, that we talked about earlier.</p> <p>18 Q You don't describe any combination of Fadavi</p> <p>19 and Mazzoni; do you?</p> <p>20 A No.</p> <p>21 But Mazzoni describes how shared memory can</p> <p>22 be allocated. He has his equations, where he talks</p> <p>23 about allocating a portion for interleaving, and then</p> <p>24 the portion right after that for de-interleaving.</p> <p>25 Q Okay. And I'll go back to that, because I --</p>

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<p style="text-align: right;">Page 571</p> <p>1 I think I heard you say that earlier, and I forgot to</p> <p>2 go back to it.</p> <p>3 But let me -- let me stick to Fadavi, because</p> <p>4 I believe that your opening expert report relies on</p> <p>5 Fadavi as disclosing shared memory.</p> <p>6 <b>A Yes.</b></p> <p>7 Q Okay. But you would agree with me, that</p> <p>8 Fadavi's disclosure does not necessarily -- well,</p> <p>9 first of all, it doesn't explicitly disclose shared</p> <p>10 memory; correct?</p> <p>11 <b>A It doesn't explicitly disclose any particular</b></p> <p>12 <b>memory implementation.</b></p> <p>13 Q Right.</p> <p>14 So it doesn't explicitly disclose shared</p> <p>15 memory; right?</p> <p>16 <b>A Or dedicated.</b></p> <p>17 Q So it doesn't explicitly disclose shared</p> <p>18 memory; correct?</p> <p>19 <b>A It doesn't explicitly disclose dedicated or</b></p> <p>20 <b>shared memory.</b></p> <p>21 Q Okay. So we talked about the issue of</p> <p>22 sessions and supporting four of them.</p> <p>23 Fadavi has this other implementation that he</p> <p>24 calls -- and it's beginning at line 25 of column 7.</p> <p>25 He has a separate implementation, where he calls it an</p>	<p style="text-align: right;">Page 573</p> <p>1 But I'm just going to ask you this question</p> <p>2 in general: So what do you understand Fadavi's</p> <p>3 opti- -- optimal implementation to be disclosing?</p> <p>4 <b>A I understand the optimal implementation to</b></p> <p>5 <b>allow additional sessions of ADSL to be supported, as</b></p> <p>6 <b>long as they have smaller interleaved depth.</b></p> <p>7 Q I'm sorry. So I think you might be mixing</p> <p>8 the two embodiments.</p> <p>9 But -- so I'm going to -- so starting at</p> <p>10 line 25, it says:</p> <p>11 "An optimal implementation of the</p> <p>12 interleaver, according to the method of the invention,</p> <p>13 utilizes the same memory for receive data and transmit</p> <p>14 data, and thus requires 20 kilobytes to support a</p> <p>15 standard ADSL session at full interleave depth (16 K</p> <p>16 interleave and de-interleave plus 4 K fast path)."</p> <p>17 Do you see that?</p> <p>18 <b>A I do.</b></p> <p>19 Q Okay. So let's focus on that sentence first.</p> <p>20 So that sentence describes that you can</p> <p>21 instead use only a total of 20, in contrast to the</p> <p>22 disclosure above that, that requires 24 kilobytes for</p> <p>23 a standard ADSL session.</p> <p>24 Do you see that?</p> <p>25 <b>A I do see that.</b></p>
<p style="text-align: right;">Page 572</p> <p>1 optimal implementation.</p> <p>2 Are you familiar with the optimal</p> <p>3 implementation in Fadavi?</p> <p>4 <b>A Yes.</b></p> <p>5 Q Okay. Are you relying on the optimal</p> <p>6 implementation for any aspects of your opinions?</p> <p>7 <b>A Yes. I believe I cited and quoted that in my</b></p> <p>8 <b>reports.</b></p> <p>9 Q Okay. So do you believe that the optimal</p> <p>10 implementation necessarily discloses shared memory?</p> <p>11 <b>A I believe that that would disclose shared</b></p> <p>12 <b>memory to a person having ordinary skill in the art.</b></p> <p>13 Q Okay. But -- and so -- and you understand</p> <p>14 that Dr. Cooklev's opinion was that the optimal</p> <p>15 implementation described in Fadavi would be inoperable</p> <p>16 if used to implement a convolutional interleaver;</p> <p>17 correct?</p> <p>18 <b>A I don't recall that specifically, sitting</b></p> <p>19 <b>here right now.</b></p> <p>20 Q Okay. Well, I may find it in a minute here,</p> <p>21 but -- and feel free to look through your -- I guess</p> <p>22 it would be your reply report on the issue of</p> <p>23 validity, where you -- to the extent that you had a</p> <p>24 contrary opinion, it would be provided. So feel free</p> <p>25 to look for that, if you want.</p>	<p style="text-align: right;">Page 574</p> <p>1 Q Okay. So if you're going to use only a total</p> <p>2 of 20 kilobytes to support a standard ADSL session at</p> <p>3 full interleave depth, and 4 K of that is fast path --</p> <p>4 so can we eliminate the 4 K fast path just for a</p> <p>5 second here?</p> <p>6 <b>A Yes.</b></p> <p>7 Q Okay. So you're left with 16 Kbyte total</p> <p>8 interleave and de-interleave memory, but you have to</p> <p>9 support a full interleave depth for a standard ADSL</p> <p>10 session.</p> <p>11 And you would agree with me, that that's</p> <p>12 16 kilobytes, correct, downstream?</p> <p>13 <b>A That is what he says.</b></p> <p>14 Q Okay. And if he's attempting to</p> <p>15 de-interleave in the same memory, he's -- he's trying</p> <p>16 to do 2 kilobytes of, I guess, upstream</p> <p>17 de-interleaving in the same memory that he's</p> <p>18 implementing 16 K of downstream interleaver, that's</p> <p>19 not going to work; is it?</p> <p>20 <b>A I think he's made a calculation error here,</b></p> <p>21 <b>because if it's only one session, it doesn't need 4 K</b></p> <p>22 <b>for the fast path. It only needs a total of</b></p> <p>23 <b>1 kilobyte for four sessions. So I'm not sure what is</b></p> <p>24 <b>going on with his math in that -- inside the parens.</b></p> <p>25 <b>But it doesn't seem like that would be right.</b></p>

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<p style="text-align: right;">Page 575</p> <p>1 Q Okay. So let's set that off as possibly</p> <p>2 being a -- you know, one mistake of Fadavi.</p> <p>3 Let's -- let's talk about the 16 K of</p> <p>4 interleave and de-interleave memory that he's</p> <p>5 apparently going to try to share.</p> <p>6 So if he has 16 kilobytes of interleave and</p> <p>7 de-interleave memory, and he's -- and he's</p> <p>8 implementing a standard ADSL session at full</p> <p>9 interleave depth, so he's using 16 K for his</p> <p>10 downstream interleaver, he's not going to be able to</p> <p>11 also use that interleaver for his -- I'm sorry -- he's</p> <p>12 not also going to be able to use any of that 16 K for</p> <p>13 an upstream de-interleaver; right?</p> <p>14 <b>A Right.</b></p> <p>15 <b>I would agree with you, which is why I think</b></p> <p>16 <b>there is a math error within those parentheses,</b></p> <p>17 <b>because above, he's -- he said interleaver for</b></p> <p>18 <b>standard ADSL requires 16 kilobytes for downstream and</b></p> <p>19 <b>2 kilobytes for upstream. And he has somehow then</b></p> <p>20 <b>lost the 2 kilobytes for upstream, and I -- it doesn't</b></p> <p>21 <b>make sense.</b></p> <p>22 Q Okay. So if he were to have a separate</p> <p>23 2 kilobytes for upstream, then again, we're back at it</p> <p>24 doesn't necessarily disclose the use of shared memory;</p> <p>25 right?</p>	<p style="text-align: right;">Page 577</p> <p>1 interleave session, or that, you know, this is going</p> <p>2 to be divided up amongst interleave sessions.</p> <p>3 We already talked about that, with respect to</p> <p>4 the, I guess, nonoptimal embodiments disclosed above</p> <p>5 line 25 of column 7; right?</p> <p>6 <b>A I think we did, yes.</b></p> <p>7 Q Okay. And we talked about how that doesn't</p> <p>8 necessarily disclose shared memory; right?</p> <p>9 <b>A Doesn't exclude it. Doesn't necessarily</b></p> <p>10 <b>exclude any particular implementation.</b></p> <p>11 Q Okay. Then, when I asked you about the</p> <p>12 optimal implementation, you originally started -- I</p> <p>13 believe you started to talk about that -- that same</p> <p>14 concept of -- of dividing an amount of memory amongst</p> <p>15 sessions, depending on how many sessions you had;</p> <p>16 right?</p> <p>17 <b>A Right.</b></p> <p>18 Q Okay. So do you -- did you have a separate</p> <p>19 theory, based on this optimal implementation that</p> <p>20 we've already -- I mean, you've recognized one</p> <p>21 potential error, and we've pointed out another</p> <p>22 potential error.</p> <p>23 But does your -- does your opinion rely on</p> <p>24 the sentence that begins on line 25 and ends on</p> <p>25 line 30?</p>
<p style="text-align: right;">Page 576</p> <p>1 <b>A It doesn't exclude the use of shared memory.</b></p> <p>2 <b>I understood this optimal implementation to be</b></p> <p>3 <b>allowing use of the -- the same memory as -- as he</b></p> <p>4 <b>discloses. It's just shown as one</b></p> <p>5 <b>interleaver/de-interleaver RAM.</b></p> <p>6 Q Okay. Right.</p> <p>7 But -- so when I asked you about the optimal</p> <p>8 implementation, the way you originally described it to</p> <p>9 me is, you went to the sentence that begins with:</p> <p>10 "With a lesser interleave depth, additional</p> <p>11 sessions may be supported with the same size buffer.</p> <p>12 With a larger buffer, additional sessions may be</p> <p>13 supported."</p> <p>14 Right?</p> <p>15 <b>A Right.</b></p> <p>16 Q But we already talked about that, with</p> <p>17 respect to the embodiments that are disclosed above,</p> <p>18 approximately line 25 in column 7; right?</p> <p>19 <b>A Which line?</b></p> <p>20 Q Approximately line 25.</p> <p>21 So -- so -- so the last two sentences that</p> <p>22 talk about sharing between sessions, potentially;</p> <p>23 right?</p> <p>24 <b>A Right.</b></p> <p>25 Q Where you -- where you might say, this is an</p>	<p style="text-align: right;">Page 578</p> <p>1 <b>A Well, he hasn't explained how he derived the</b></p> <p>2 <b>required sizes of the interleave -- interleaver and</b></p> <p>3 <b>de-interleaver memory portions. He hasn't explained</b></p> <p>4 <b>what the maximum value of I and the maximum value of D</b></p> <p>5 <b>would be.</b></p> <p>6 <b>So the way I interpreted that calculation is,</b></p> <p>7 <b>he just assumed a convolutional interleaver with no</b></p> <p>8 <b>particular implementation.</b></p> <p>9 <b>And then the optimal implementation would</b></p> <p>10 <b>have a more memory-efficient implementation, such as</b></p> <p>11 <b>the triangular approach that we talked about earlier.</b></p> <p>12 Q Okay. But if he has a -- so are you</p> <p>13 suggesting, for example, his 16 K full interleave</p> <p>14 depth in a nonoptimal implementation is not doing</p> <p>15 triangular interleaving and requires 16 K?</p> <p>16 And then you're suggesting that maybe he's</p> <p>17 decided to use now a triangular one, so he's going to</p> <p>18 only need 8 K for a full interleave depth standard</p> <p>19 ADSL session?</p> <p>20 <b>A Well, he doesn't explain how he's computed</b></p> <p>21 <b>these values, or what kind of implementation he's</b></p> <p>22 <b>done. But there is a -- an implication in that last</b></p> <p>23 <b>part of that paragraph that something has changed to</b></p> <p>24 <b>make it a more optimal implementation.</b></p> <p>25 Q Okay. If you could go to your reply expert</p>



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<p style="text-align: right;">Page 579</p> <p>1 report. And that is exhibit -- what exhibit is that?</p> <p>2 <b>A 24.</b></p> <p>3 Q Okay. Exhibit 24.</p> <p>4 And you could -- if you could go to, for</p> <p>5 example, page 85.</p> <p>6 <b>A (Witness complies.)</b></p> <p>7 Q And in paragraph 265, you state that:</p> <p>8 "Dr. Cooklev asserts that the optimal</p> <p>9 implementation described by Fadavi-Ardekani would be</p> <p>10 inoperable with G.993.1."</p> <p>11 Citing Cooklev report at paragraph 298.</p> <p>12 "Without any citation to Fadavi-Ardekani,</p> <p>13 Dr. Cooklev argues that, 'Fadavi discloses that the</p> <p>14 same memory is used for receive and transmit data</p> <p>15 alternately, and that the receive interleave data will</p> <p>16 be overwritten with interleave data that must be</p> <p>17 interleaved and transmitted."</p> <p>18 Do you see that?</p> <p>19 <b>A I do.</b></p> <p>20 Q You respond by saying:</p> <p>21 "Dr. Cooklev has mischaracterized the</p> <p>22 disclosure of Fadavi-Ardekani. The portions of</p> <p>23 Fadavi-Ardekani, to which he appears to refer, concern</p> <p>24 the use of the frame buffer, not the</p> <p>25 interleave/de-interleave memory (IDIM), which is a</p>	<p style="text-align: right;">Page 581</p> <p>1 <b>Fadavi-Ardekani posed for the nonoptimal</b></p> <p>2 <b>implementation.</b></p> <p>3 <b>And I think that a person, having ordinary</b></p> <p>4 <b>skill in the art, would interpret that as disclosing</b></p> <p>5 <b>the use of shared memory.</b></p> <p>6 Q Okay. But if it uses the same memory for</p> <p>7 receive data and transmit data, in other words, uses</p> <p>8 the same memory for an interleaver and a</p> <p>9 de-interleaver, and it implements a session at full</p> <p>10 interleave depth, is that possible to use the same</p> <p>11 memory for interleaving and de-interleaving?</p> <p>12 <b>A That's what Fadavi-Ardekani says.</b></p> <p>13 Q That's what he says.</p> <p>14 But you, as an expert with skill in the art,</p> <p>15 as you purport to be, do you think that maybe he's</p> <p>16 wrong, and he hasn't thought through that you can't</p> <p>17 implement an interleaver and a de-interleaver where</p> <p>18 you're overwriting the interleave data bytes with</p> <p>19 de-interleave data bytes?</p> <p>20 <b>A But it doesn't say that you're overwriting</b></p> <p>21 <b>the data bytes.</b></p> <p>22 Q Okay. If I were to tell you -- I came to</p> <p>23 you. I want to design my own modem. And I said, I'm</p> <p>24 going to put together a device that has -- and I'm</p> <p>25 going to rely on your expertise. I'm going to say,</p>
<p style="text-align: right;">Page 580</p> <p>1 separate memory."</p> <p>2 Do you see that?</p> <p>3 <b>A I do.</b></p> <p>4 Q So what frame buffer are you talking about?</p> <p>5 <b>A If you look at column 8 of Fadavi-Ardekani.</b></p> <p>6 <b>And -- and again, Dr. Cooklev did not cite</b></p> <p>7 <b>anything in Fadavi-Ardekani, so I had to go hunting.</b></p> <p>8 <b>But the only place I saw in Fadavi-Ardekani,</b></p> <p>9 <b>that talks about data being overwritten, is at the top</b></p> <p>10 <b>of column 8 in the context of the frame buffer, which</b></p> <p>11 <b>is a different memory than the</b></p> <p>12 <b>interleave/de-interleave memory.</b></p> <p>13 Q Okay. So -- so it appears that you and</p> <p>14 Dr. Cooklev may have talked past each other on this</p> <p>15 particular point.</p> <p>16 <b>A Okay.</b></p> <p>17 Q So let me try to clear it up here. That's</p> <p>18 what I'm attempting to do here. So I -- I -- so let</p> <p>19 me go back to the -- the basic question.</p> <p>20 Are you relying on the sentence that begins</p> <p>21 at 25 of column 7 and runs through line 30 of column 7</p> <p>22 as disclosing shared memory as construed by the Court?</p> <p>23 <b>A Well, that sentence, as written, suggests</b></p> <p>24 <b>that there is an opt- -- optimal implementation in</b></p> <p>25 <b>which less than the sum of the amounts that</b></p>	<p style="text-align: right;">Page 582</p> <p>1 I'm going to put together a device that -- with only</p> <p>2 16 K of memory. And I want to be able to do an</p> <p>3 interleaver that requires 16 K of memory, and a</p> <p>4 de-interleaver that requires 2 K of memory, and I want</p> <p>5 to be able to use those maximum depths of -- the</p> <p>6 depths at the same time.</p> <p>7 Would you tell me I'm crazy?</p> <p>8 Would you tell me I can't do that?</p> <p>9 <b>A You said I -- that you only want 16 K of</b></p> <p>10 <b>memory, but you need 20?</b></p> <p>11 Q I -- I get -- well, I was excluding fast path</p> <p>12 for the moment.</p> <p>13 But let's say that I -- that I'm only worried</p> <p>14 about doing an interleaver and a de-interleaver.</p> <p>15 <b>A Okay.</b></p> <p>16 Q And I want to do convolutional interleaving</p> <p>17 with simultaneous downstream communication and</p> <p>18 upstream communication.</p> <p>19 <b>A Okay.</b></p> <p>20 Q And I want -- I need -- and I -- and my</p> <p>21 implementation is going to require 2 K of upstream</p> <p>22 memory and 16 K of downstream memory. And I tell you</p> <p>23 I'm going to do that all in the same 16 K memory.</p> <p>24 What would you advise me?</p> <p>25 <b>A I would advise you that you'd need to change</b></p>

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<p style="text-align: right;">Page 583</p> <p>1 <b>your implementation.</b></p> <p>2 Q Okay. So I agree with you, if Fadavi doesn't</p> <p>3 say it's broken.</p> <p>4 But does that necessarily mean it's not</p> <p>5 broken?</p> <p>6 <b>A It doesn't necessarily mean one or the other.</b></p> <p>7 <b>He -- he does repeat that. If it's a mistake, he</b></p> <p>8 <b>repeats it, because he says 20 kilobytes, and then the</b></p> <p>9 <b>amount adds up to 20 kilobytes.</b></p> <p>10 Q Right.</p> <p>11 And he's going to -- and he's intending to</p> <p>12 support standard ADSL at full interleave depth.</p> <p>13 And you agree with me that -- that standard</p> <p>14 A -- A -- standard ADSL, at full interleave depth,</p> <p>15 requires 16 K of interleave memory; right?</p> <p>16 <b>A Well, that's what Fadavi-Ardekani says.</b></p> <p>17 Q Okay. And standard ADSL at full</p> <p>18 de-interleave depth, I guess we're talking about</p> <p>19 the -- the CO equipment, requires 2 kilobytes; right?</p> <p>20 <b>A That's what he says.</b></p> <p>21 Q Okay. So if I'm going to try to implement</p> <p>22 both of those at the same time in only 16 K of</p> <p>23 interleave/de-interleave memory, is that possible?</p> <p>24 <b>A Yes, assuming that, in calculating the</b></p> <p>25 <b>16 kilobytes and the 2 kilobytes, you just assumed</b></p>	<p style="text-align: right;">Page 585</p> <p>1 maximum interleave depth end to end in G.992.1?</p> <p>2 <b>A I don't know that off the top of my head.</b></p> <p>3 Q Do you know whether Fadavi contemplated a</p> <p>4 triangular interleaver or some other implementation?</p> <p>5 <b>A I don't know. It was 2000. Triangular</b></p> <p>6 <b>approaches were definitely known by then.</b></p> <p>7 Q Okay. So you've inserted in here some --</p> <p>8 some uncertainty over what his implementation is.</p> <p>9 But let's -- let's go back to what Fadavi</p> <p>10 actually says. So Fadavi says he wants to use the</p> <p>11 same memory for receive data and transmit data, and</p> <p>12 thus requires -- requires -- 20 kilobytes to support a</p> <p>13 standard ADSL session; right?</p> <p>14 <b>A I see that.</b></p> <p>15 Q So he's -- he's contemplating something that</p> <p>16 necessarily needs 16 K of interleave memory to</p> <p>17 implement a full ADSL session; right?</p> <p>18 <b>A Are you talking about his parentheses?</b></p> <p>19 Q I'm talking about the entire sentence.</p> <p>20 He's -- he's saying what it requires.</p> <p>21 <b>A That is what he says.</b></p> <p>22 Q Okay. So he's not contemplating using half</p> <p>23 of the required memory; is he?</p> <p>24 <b>A Not explicitly, no.</b></p> <p>25 Q Okay. Let me ask you -- let me ask the</p>
<p style="text-align: right;">Page 584</p> <p>1 <b>a -- an ordinary convolutional interleaver approach.</b></p> <p>2 <b>And then you could have those numbers by implementing</b></p> <p>3 <b>using a more efficient approach, such -- such as a</b></p> <p>4 <b>triangular interleaver.</b></p> <p>5 Q Okay. But then -- but then, in that case,</p> <p>6 you wouldn't be using the same memory for interleaving</p> <p>7 and de-interleaving; right?</p> <p>8 <b>A It -- I understand same memory to mean same</b></p> <p>9 <b>block of memory that you can allocate to interleaving</b></p> <p>10 <b>or de-interleaving, depending on what you need.</b></p> <p>11 Q Okay. So let's start with: Fadavi doesn't</p> <p>12 disclose that he's using a triangular interleaver;</p> <p>13 correct?</p> <p>14 <b>A He doesn't disclose any particular</b></p> <p>15 <b>implementation.</b></p> <p>16 Q Okay. And a standard DSL session at full</p> <p>17 interleave depth, are you saying that that is</p> <p>18 16 kilobytes of end-to-end delay?</p> <p>19 <b>A It's -- this is given in terms of a quantity</b></p> <p>20 <b>of memory. So the end-to-end delay would be twice</b></p> <p>21 <b>that, at least.</b></p> <p>22 Q My -- my question for you is: What is --</p> <p>23 what is a -- what is a full interleave depth for</p> <p>24 standard ADSL?</p> <p>25 What is the full -- what is -- what is the</p>	<p style="text-align: right;">Page 586</p> <p>1 question this way.</p> <p>2 So set aside what standard ADSL is. Let's</p> <p>3 talk about a hypothetical DSL system, given the</p> <p>4 technologies that you're aware of, inclusive of</p> <p>5 triangular interleavers.</p> <p>6 Let's talk about a device that must support</p> <p>7 20 kilo- -- 20 kilobytes of delay downstream, and just</p> <p>8 to keep it simple, 20 kilobytes of delay upstream;</p> <p>9 okay?</p> <p>10 And so, with a triangular interleaver, I</p> <p>11 guess that would require at least 10 kilobytes of</p> <p>12 memory for upstream and 10 kilobytes of memory for</p> <p>13 downstream; right?</p> <p>14 <b>A That's correct.</b></p> <p>15 Q Okay. Could I implement that device at full</p> <p>16 downstream interleave depth and full upstream</p> <p>17 de-interleave depth with only 15 kilobytes of total</p> <p>18 memory?</p> <p>19 <b>A No.</b></p> <p>20 Q So there -- so there wouldn't be any way to</p> <p>21 temporarily use some of the bytes for downstream for</p> <p>22 upstream?</p> <p>23 <b>A Not that I'm aware of.</b></p> <p>24 Q Okay. Certainly not with a convolutional</p> <p>25 interleaver; right?</p>

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<p style="text-align: right;">Page 587</p> <p>1     <b>A I can't think of a way you would do it.</b></p> <p>2     MR. MCANDREWS: Okay. We can take a short</p> <p>3     break here.</p> <p>4     THE VIDEOGRAPHER: Going off the record. The</p> <p>5     time is now 3:21.</p> <p>6     (Recess taken.)</p> <p>7     THE VIDEOGRAPHER: Going on the record. The</p> <p>8     time is now 3:26.</p> <p>9     MR. MCANDREWS: Okay.</p> <p>10    Q Again, back to this sentence that begins on</p> <p>11    column 7 of Fadavi and runs through line 30.</p> <p>12    Is Dr. Cooklev wrong to have concluded that,</p> <p>13    if this is attempting to implement full 16 K</p> <p>14    interleaver and a 2 K de-interleaver in the same</p> <p>15    16 kilobytes of memory, it would be broken?</p> <p>16    <b>A Well, again, it would depend on whether --</b></p> <p>17    <b>are you saying whatever implementation requires 16 K</b></p> <p>18    <b>of interleave memory and 2 K of de-interleave memory?</b></p> <p>19    <b>Is that the hypothetical?</b></p> <p>20    Q Yes.</p> <p>21    <b>A And you're trying to implement it in only</b></p> <p>22    <b>16 K of memory?</b></p> <p>23    Q Right.</p> <p>24    Is Dr. Cooklev wrong to conclude that that's</p> <p>25    inoperable?</p>	<p style="text-align: right;">Page 589</p> <p>1     WITNESS AFFIDAVIT</p> <p>2</p> <p>3</p> <p>4</p> <p>5     _____</p> <p>6     KRISTA S JACOBSEN</p> <p>7</p> <p>8     SUBSCRIBED AND SWORN BEFORE ME</p> <p>9     THIS ____ DAY OF _____, 2019</p> <p>10    _____</p> <p>11    (Notary Public) MY COMMISSION EXPIRES ON: _____</p> <p>12</p> <p>13</p> <p>14</p> <p>15</p> <p>16</p> <p>17</p> <p>18</p> <p>19</p> <p>20</p> <p>21</p> <p>22</p> <p>23</p> <p>24</p> <p>25</p>
<p style="text-align: right;">Page 588</p> <p>1     <b>A Under that hypothetical, he would not be</b></p> <p>2     <b>wrong.</b></p> <p>3     MR. MCANDREWS: Okay. I have no further</p> <p>4     questions at this time.</p> <p>5     MS. WALSH: Nothing from me.</p> <p>6     MR. MCANDREWS: Okay. Thank you very much.</p> <p>7     THE WITNESS: Thank you.</p> <p>8     THE VIDEOGRAPHER: This marks the end of</p> <p>9     Videotape No. 3, Volume III.</p> <p>10    This is the conclusion of today's deposition.</p> <p>11    The time is now 3:28. We are off the record.</p> <p>12    (WHEREUPON, the deposition ended</p> <p>13    at 3:28 p.m.)</p> <p>14    ---oOo---</p> <p>15</p> <p>16</p> <p>17</p> <p>18</p> <p>19</p> <p>20</p> <p>21</p> <p>22</p> <p>23</p> <p>24</p> <p>25</p>	<p style="text-align: right;">Page 590</p> <p>1     CERTIFICATE OF REPORTER</p> <p>2</p> <p>3     I, ANDREA M IGNACIO, hereby certify that the</p> <p>4     witness in the foregoing deposition was by me duly</p> <p>5     sworn to tell the truth, the whole truth, and nothing</p> <p>6     but the truth in the within-entitled cause;</p> <p>7     That said deposition was taken in shorthand</p> <p>8     by me, a disinterested person, at the time and place</p> <p>9     therein stated, and that the testimony of the said</p> <p>10    witness was thereafter reduced to typewriting, by</p> <p>11    computer, under my direction and supervision;</p> <p>12    That before completion of the deposition,</p> <p>13    review of the transcript [ ] was [x] was not</p> <p>14    requested If requested, any changes made by the</p> <p>15    deponent (and provided to the reporter) during the</p> <p>16    period allowed are appended hereto</p> <p>17    I further certify that I am not of counsel or</p> <p>18    attorney for either or any of the parties to the said</p> <p>19    deposition, nor in any way interested in the event of</p> <p>20    this cause, and that I am not related to any of the</p> <p>21    parties thereto</p> <p>22    Dated: _____</p> <p>23    _____</p> <p>24    ANDREA M IGNACIO, RPR, CRR, CCRR, CLR, CSR No 9830</p> <p>25</p>

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1	ERRATA SHEET				
2					
3	Case Name: TQ Delta v. 2Wire Inc.				
4	Deposition Date: 2-6-19				
5	Deponent: Krista S. Jacobsen, Ph.D., Volume III				
6					
7	Pg.	No.	Now Reads	Should Read	Reason
8	_____	_____	_____	_____	_____
9	_____	_____	_____	_____	_____
10	_____	_____	_____	_____	_____
11	_____	_____	_____	_____	_____
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20	_____	_____	_____	_____	_____
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25	_____	_____	_____	_____	_____

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# **EXHIBIT 14**



LB-031

ITU - Telecommunication Standardization Sector

Temporary Document LB-031

STUDY GROUP 15

Original: English

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**Leuven – 14-18 June 2004**

Question: 4/15

SOURCE<sup>1</sup>: Texas Instruments, Inc.TITLE: **VDSL2 – Constraining the Interleaver Complexity**

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**Abstract**

This contribution proposes restrictions on the interleaver. The interleaver is a major source of complexity in VDSL2. We propose that the interleaver delay in time be restricted rather than restricting the depth as in ADSL2. This allows the following: 1) the flexibility of using shorter codewords to correct longer bursts, 2) the capability to correct repetitive impulse noise, and 3) lower complexity implementations for profiles that do not require the full VDSL2 data rate. We propose also that the upper limit on the number of codewords in a DMT symbol (or per unit time) scale with the data rate so that more codewords are allowed at higher data rates.

Introduction, Limits on Interleaver Complexity, Limits on the Number of Codewords, Repetitive Impulse Noise, Examples, Proposal, References

**Differences**

As a courtesy to those who may have read T1E1.4/2003-493, this section lists the differences between this contribution and that one.

- generally, this contribution proposes that the number of codewords in a given amount of time and the interleaver complexity should both scale with the data rate
- the substance of the introduction has not changed
- section 2 (limits on interleaver complexity): *an example is included to illustrate practically how this proposal would work in the recommendation*
- section 3 (limits on the number of codewords): *this section has been completely revised*
- section 4 (repetitive impulse noise): this section has not changed
- section 5 (examples) *the table has been revised*
- section 6 (proposal) *the proposals have been revised*
- section 7 (references) *the references have been updated*

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## 1. Introduction

A convolutional interleaver was first described by Ramsey [1] and Forney [2]. In general, a convolutional interleaver imposes a different delay on each input symbol (normally an octet). If  $i$  denotes the octet index within a group of  $I$  octets so that  $i = 0, 1, \dots, I-1$ , octet  $i$  experiences a delay of  $i \cdot (d-1)$  with  $d$  the interleaver depth. The deinterleaver performs the inverse operation delaying octet  $i$  by  $(I-i-1) \cdot (d-1)$ . The overall delay of the interleaver/deinterleaver pair is

$$\text{interleaver delay (octets)} = (I-1) \cdot (d-1) \text{ octets.} \quad (1)$$

This applies to all interleavers being considered for VDSL2.

The smallest amount of memory required to build an interleaver/deinterleaver pair is equal to the total delay of the interleaver/deinterleaver [3]. Typically, for memory optimized interleavers, the interleaver and deinterleaver memory size is nearly the same. Therefore, the smallest possible memory for either the interleaver or deinterleaver is

$$\text{smallest possible (de)interleaver memory} = (I-1) \cdot (d-1)/2 \text{ bytes.} \quad (2)$$

In a typical implementation, slightly more memory is often required. The actual amount of required memory is implementation specific.

The length of a burst that can be corrected by the combination of Reed-Solomon coding and interleaving/deinterleaving is dependent on the line data rate. We define  $ldr$  as the line data rate, the rate of the Reed-Solomon encoded bits. This is as opposed to the net data rate,  $ndr$ , the effective payload data rate as seen at the  $\alpha(\beta)$  interface between the TPS-TC and the PMS-TC. We adopt the notation  $ldr\_mbit\_s$  or  $ldr\_kbit\_s$  to indicate whether the data rate is given in mbit/s or kbit/s respectively. The line data rate and net data rate are related by the equation

$$ndr\_kbit\_s = ldr\_kbit\_s * (n-r)/n - \text{overhead rate} \quad (3)$$

where the Reed-Solomon codeword size is  $n$  octets with  $r$  octets of redundancy.

For a  $t$  error correcting (typically  $t = r/2$ ) Reed-Solomon code of size  $n$  octets, and assuming  $n = I \cdot q^2$ , the combination of coding and interleaving can correct a burst of

$$INP\_min = t \cdot d / q \text{ octets} \Rightarrow t \cdot d / q \cdot 8 / ldr\_mbit\_s \mu s. \quad (4)$$

In ADSL2 and ADSL2+,  $q = 1$ ,  $t$  is up to 8 (assuming erasure decoding is not used),  $n$  is up to 255 and  $d$  can be up to 64 downstream and 8 upstream. In ADSL2+, the maximum line data rate is 24.48 Mbps. At this rate the coding plus interleaving can correct up to  $8 \cdot 64 / 1 \cdot 8 / 24.48 = 167 \mu s$ .

The end-to-end delay of the interleaver/deinterleaver in ms is

$$\text{delay (ms)} = (I-1) \cdot (d-1) \cdot 8 / ldr\_kbit\_s \quad (5)$$

and for ADSL2+, the delay at the maximum line data rate is  $(255-1) \cdot (64-1) \cdot 8 / 24480 = 5.23 \text{ ms}$ .

Error bursts must be separated in time so that each codeword corrects only one burst. The span of a codeword of size  $n$  octets and an interleaver depth,  $d$ , is

$$\text{span (ms)} = n \cdot d / q \cdot 8 / ldr\_kbit\_s \quad (6)$$

The time spacing between codewords in equation (6) is nearly identical to the interleaver delay in equation (5) for large codeword size and depth since  $n = I \cdot q$ .

<sup>2</sup> Here, “ $q$ ” is assumed to be an integer. This is not the same  $q$  used to describe the DMT tone spacing.



At the maximum codeword size, interleaver depth, and line data rate in ADSL2+, the codeword spans  $(255) \cdot (64) \cdot 8 / 24480 = 5.33$  ms. At the maximum line data rate and codeword size, the ADSL2+ coding + interleaver can correct a 167 $\mu$ s burst every 5.33 ms.

Equations (2), (4), (5), and (6) illustrate trade-offs between interleaver memory, error correction capability, delay, and burst separation. More interleaver memory normally allows more error correction but leads to higher delays and a longer separation between error bursts. Significant error correction can be achieved by using shorter codewords requiring less memory, less delay, and shorter time between bursts. However, small codewords typically have lower net coding gain and higher computation requirements since there are more decoder operations required in the same amount of time. Therefore, we make a trade-off between complexity, capability, and performance.

## 2. Limits on Interleaver Complexity

The size of the interleaver memory will be a major source of complexity in VDSL2. 100 Mbit/s symmetric has been an often stated goal for VDSL2. However, a number of operators have stated their requirements at well below 100 Mbit/s. See for example [4] or [5].

Therefore, it seems prudent to define the interleaver complexity requirements in a way that will allow those who want to deploy VDSL2 at lower speeds to do so at a reduced complexity with respect to higher speed implementations.

The way to do this and to guarantee some minimum level of performance is to specify the interleaver complexity in terms of the delay in time. From equation (5), we see that the delay in time (ms) is proportional to the interleaver depth and to the codeword size and inversely proportional to the data rate.

ADSL2 instead specifies the smallest maximum interleaver depth and the maximum number of codewords allowed in a DMT symbol. There are two problems with this approach. The first is that it removes the flexibility of trading codeword size and interleaver depth to allow more error correction with the same amount of memory. The second problem is that as the data rate increases, the interleaver delay decreases and with it, the error correction capability decreases also.

One possible way to specify the smallest maximum supported delay is to start with ADSL2+ and require that VDSL2 interleavers support *at least* 5.23ms delay. This maintains a level of impulse noise protection as the data rate increases and still allows lower speed implementations to save complexity.

For interoperability reasons, the VTU-O and VTU-R must exchange the interleaver delay in terms of octets. The requirement is that the interleaver delay in octets be sufficient to satisfy the smallest maximum delay even at the highest supported data rate. If a VDSL2 implementation supports a larger interleaver memory than is required, it should be free to specify the larger value. The VTU-O and VTU-R would then select the smaller of the transmitter and receiver capabilities, in each direction, as the end-to-end capabilities.

Again, the actual amount of memory required is implementation specific.

**Example:**

Suppose a VDSL2 transceiver supports up to 44.5 Mbit/s as a line data rate. If the minimum interleaver delay requirement were 5.23ms, then, from equation (5) and equation (1), this transceiver must support a delay of at least 29092 octets which corresponds to having an interleaver memory of *at least* 14546 octets according to equation (2) (although this is actually implementation specific). During initialization, the VDSL2 transceiver would indicate that it could support up to 44.5 Mbit/s and 29092 or more octets of interleaver delay. The actual interleaver delay could be considerably higher than 5.23ms, in this example, if the actual connection data rate is below 44.5 Mbit/s. For example, if the actual connection line rate were 5 Mbit/s, the interleaver delay could be as high as 47 ms using 14546 octets of interleaver memory. This is why the maximum delay is still needed.

Transceiver capabilities exchanged during initialization for this example:

- **maximum data rate = 44.5 Mbit/s**
- **minimum data rate = any value at or below the maximum data rate**
- **maximum delay supported  $\geq$  29092 octets**
  - meets 5.23 ms example minimum requirement
  - minimum amount of memory required for (de)interleaver is 14546 octets
- **maximum delay = any valid value as in ADSL2 today §**

**3. Limits on the Number of Codewords**

Similar to the interleaver delay, we propose that the maximum number of codewords in a DMT symbol (or per unit time) also scale with the data rate. The higher the data rate, the more DMT codewords there can be in a fixed length DMT symbol.

In ADSL2+, 5.23ms delay allows correction of an impulse burst of only 167 $\mu$ s. This is because the (de)interleaver depth is limited to 64. By removing the depth restriction, the correction capability can be increased without increasing the delay in ms or the size of the (de)interleaver.

The correction capability can be enhanced by using smaller codewords. This implies there are more codewords in each DMT symbol and a larger interleaver depth. Typically the complexity increase from adding interleaver memory is considerably higher than the complexity from decoding small codewords.

Small codewords with the codeword size,  $n$ , less than 255 can lead to slightly lower net coding gain depending on the situation. As the codeword size decreases, the gross coding gain increases since a higher percentage of errors are corrected. However, at the same time, there is more overhead. Typically for very small codeword sizes, the penalty from the overhead starts to outweigh the added benefits from more error correction capability and we see a net coding gain loss. A trade-off needs to be made between performance, delay, and complexity. This trade-off needs to take into account that a majority of lines are not afflicted by large impulse noise.

At a given interleaver delay expressed in time and a given amount of impulse noise protection, the maximum codeword size allowed is fixed. To see this, we re-write equation (4) as

$$ldr\_mbit\_s = \frac{t \cdot \frac{d}{q} \cdot 8}{INP\_min\_us} \quad (7)$$

and then insert this into equation (5) and find

$$\begin{aligned}
\text{delay}(ms) &= \frac{\left(\frac{n}{q} - 1\right)(d - 1) \cdot 8 \cdot \text{INP\_min\_ms}}{t \cdot \frac{d}{q} \cdot 8} \\
&\cong \frac{\frac{n}{q} \cdot d \cdot 8 \cdot \text{INP\_min\_ms}}{t \cdot \frac{d}{q} \cdot 8} \\
&= \frac{n \cdot \text{INP\_min\_ms}}{t}
\end{aligned} \tag{8}$$

where in the second line we assume that  $n/q$  and  $d \gg 1$  and we have substituted  $I = n/q$ . As we see, at a fixed error correction capability,  $t$ , and a fixed impulse noise correction requirement,  $\text{INP\_min\_ms}$ , the codeword size  $n$  is constrained by the delay.

With a fixed codeword size, the number of codewords in a fixed time period or in a DMT symbol will scale with the data rate. Therefore, we propose that the constraint on the number of codewords per unit time (or for a DMT symbol) scale with data rate.

For example, to achieve  $\text{INP\_min\_us} = 500$  (2 DMT symbols if the DMT symbol rate is 4000) at  $t = 8$  and a delay constraint of 5.23ms, we need  $n \approx 85$ . The number of codewords in a 4 kHz DMT symbol is

$$\begin{aligned}
\text{codewords per 4 kHz DMTsymbol} &= \text{ldr\_kbit\_s} \cdot \frac{1 \text{ octet}}{8 \text{ bits}} \cdot \frac{1 \text{ codeword}}{n \text{ octets}} \cdot \frac{1 \text{ s}}{4 \text{ k DMT symbols}} \\
&= \frac{\text{ldr\_kbit\_s}}{32 \cdot n} \\
&= \frac{\text{ldr\_kbit\_s}}{2720}
\end{aligned} \tag{9}$$

At a line data rate of 30 mbit/s (30000 kbit/s), for example, the number of codewords per 4 kHz DMT symbol is  $\frac{30000}{2720} = 11.03 \rightarrow 12$ .

Putting this in ADSL2 terms with  $S$  defined as the number of DMT symbols per codeword, we would say

$$S \geq \frac{2720}{\text{ldr\_kbit\_s}} \tag{10}$$

where  $n = 85$  and  $t = 8$  was used to constrain  $S$ . For the example at 30 Mbit/s, this would be  $S \geq 1/12$ .

Since variable tone spacing and a variable cyclic extension length will cause the DMT symbol period to vary from 4000 Hz, this rule on the number of codewords per DMT symbol needs to be specified in a way that allows a variable DMT symbol period. We leave this for a future meeting.

This does not mean that  $n = 85$  would be the largest or smallest codeword size allowed, it is simply used to guarantee a certain minimum level of impulse noise protection at a given minimum interleaver delay at a given maximum data rate. If the actual interleaver delay is higher or the data rate lower or the impulse noise protection lower, larger codewords can be used. The proposal is that  $S_{\min}$  scale with the data rate. In ADSL2,  $S_{\min}$  is fixed at  $\frac{1}{2}$  and in ADSL2+,  $S_{\min}$  is fixed at  $\frac{1}{3}$ .

#### 4. Repetitive Impulse Noise

Recently, impulse noise measurements taken by BT [6] have shown that some faulty or poorly designed consumer electronic equipment can emit 100 Hz noise pulses. Presumably, in North America, we would find similar 120 Hz noise sources although we are not aware of a comparable study. If 120 Hz noise sources exist, the period of the disturbance would be 8.33ms. To correct an impulse that occurs every 8.33ms, each Reed-Solomon codeword must span no more than 8.33ms or be designed so that each codeword can correct multiple bursts.

Noting the similarity between equations (5) and (6), as long as the length of each impulse falls within the correction capability of the Reed-Solomon code plus interleaver, the impulse train can be corrected as long as the interleaver delay is less than about 8.33ms in regions with 60Hz power transmission or 10ms in regions that use 50Hz power transmission.

#### 5. Examples

net data rate ( <i>ndr_mbit_s</i> )	line data rate ( <i>ldr_mbit_s</i> )	delay(ms)	interleaver depth ( <i>d</i> ) for $q = 1$	number of codewords per 4000Hz DMT symbol (1/ <i>S</i> )	optimal (de)interleaver memory size (octets) $[(I - 1)*(d - 1)/2]$	impulse noise protection
100	123.5	5.18	966	46	40048	500 $\mu$ s
36	44.5	5.17	348	17	14400	500 $\mu$ s
25	30.1	5.17	242	12	10002	500 $\mu$ s
20	24.4	5.23	191	9	8001*	500 $\mu$ s
* ADSL2/2+ minimum memory requirement.						

#### 6. Proposal

This contribution addresses

11.4	Open	What shall be the mandatory interleaver capabilities?	MC-086, D1060
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and proposes:

- interleaver complexity should be specified in terms of a time delay (ms), not in terms of an amount of memory or an interleaver depth
- interleaver delay in terms of octets should be exchanged between the VTU-O and VTU-R; the delay in octets should meet the minimum requirements in terms of the delay in time
- the upper limit on the number of codewords per unit time should be constrained and should scale with the data rate so that as the data rates increase, this upper limit on the number of codewords is also higher

#### 7. References

- [1] Ramsey, J.L., "Realization of Optimum Interleavers", in *IEEE Trans Info Theory*, Vol IT-16, No. 3, May 1970, pp. 338-345.
- [2] Forney, G.D., "Burst-Correcting Codes for the Classic Bursty Channel", *IEEE Trans Communications Technology*, Vol COM-19, October 1971, pp. 772-781.

**LB-031**

- [3] Heegard, C. and Wicker, S.B., "Turbo Coding," Kluwer Academic Publishers, Boston, MA, 1999.
- [4] Foster, K., "VDSL2 Requirements," ITU Temporary Document SS-058, January 2004.
- [5] Starr, T. and Wei, D., "VDSL2 Rate and Reach Goals," ITU Delayed Contribution 1045, April 2004.
- [6] Foster, K., "Improved Impulse Noise Modelling for xDSL Modem Testing," ITU Delayed Contribution 1251, April 2004.

# **EXHIBIT 15**



US007269208B2

(12) **United States Patent**  
**Mazzoni et al.**

(10) **Patent No.:** **US 7,269,208 B2**

(45) **Date of Patent:** **Sep. 11, 2007**

(54) **DEVICE FOR SENDING/RECEIVING  
DIGITAL DATA CAPABLE OF PROCESSING  
DIFFERENT BIT RATES, IN PARTICULAR  
IN A VDSL ENVIRONMENT**

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**Hélène Came**, Grenoble (FR)

(73) Assignee: **STMicroelectronics SA**, Montrouge  
(FR)

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(22) PCT Filed: **Jul. 11, 2001**

(86) PCT No.: **PCT/FR01/02243**

§ 371 (c)(1),  
(2), (4) Date: **Jul. 16, 2002**

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PCT Pub. Date: **Jan. 24, 2002**

(65) **Prior Publication Data**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**

**H04B 1/38** (2006.01)

**H04L 5/16** (2006.01)

(52) **U.S. Cl.** ..... **375/219**

(58) **Field of Classification Search** ..... 375/219,  
375/222, 259, 377; 714/701, 702, 761, 762,  
714/763

See application file for complete search history.

(56) **References Cited**

#### U.S. PATENT DOCUMENTS

4,559,625 A \* 12/1985 Berlekamp et al. .... 714/701  
5,751,741 A \* 5/1998 Voith et al. .... 714/758  
5,764,649 A \* 6/1998 Tong ..... 714/701  
5,912,898 A \* 6/1999 Khoury ..... 714/701  
6,956,872 B1 \* 10/2005 Djokovic et al. .... 370/505

#### FOREIGN PATENT DOCUMENTS

EP 0856949 8/1998

#### OTHER PUBLICATIONS

Veithen et al., A 70MB/S Variable-Rate DMT-Based Modem for VDSL, IEEE International Solid State Circuits Conference, IEEE Inc. New York, US, vol. 42, Feb. 1999, pp. 248-249, XP000862325. Patent Abstracts of Japan, vol. 1997, No. 02, Feb. 28, 1997 & JP 08265177 Oct. 11, 1996.

\* cited by examiner

*Primary Examiner*—David C. Payne

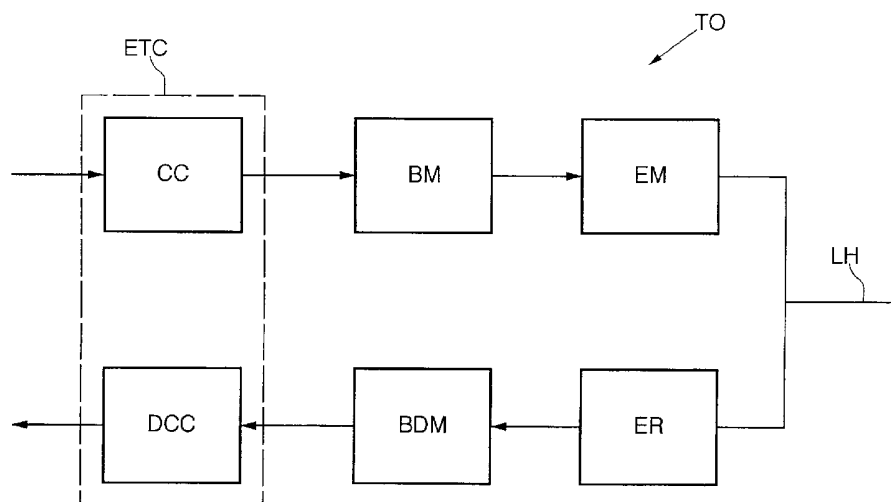
*Assistant Examiner*—Nader Bolourchi

(74) *Attorney, Agent, or Firm*—Lisa K. Jorgenson; Allen, Dyer, Doppelt, Milbrath & Gilchrist, P.A.

(57) **ABSTRACT**

A device for sending/receiving digital data is capable of processing different bit rates from a group of predetermined bit rates. The device may include a channel coding/decoding stage including an interleaver, a deinterleaver, and a memory whose minimum size is fixed as a function of the maximum bit rate of the group of predetermined bit rates. The memory may have a first memory space assigned to the interleaver and a second memory space assigned to the deinterleaver. The size of each of the two memory spaces may be set as a function of the bit rate actually processed by the device.

**15 Claims, 7 Drawing Sheets**



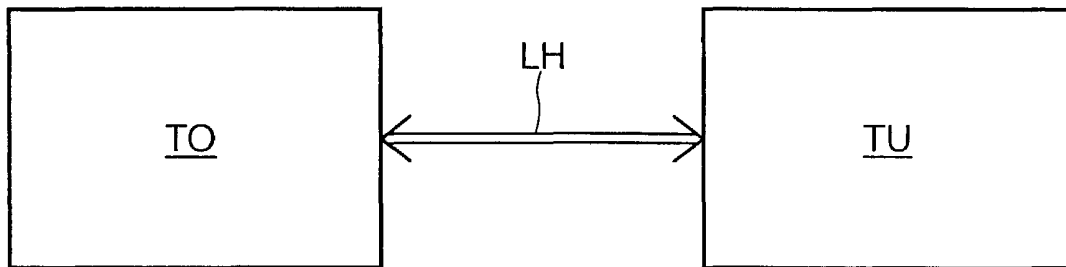
**U.S. Patent**

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**FIG.1**





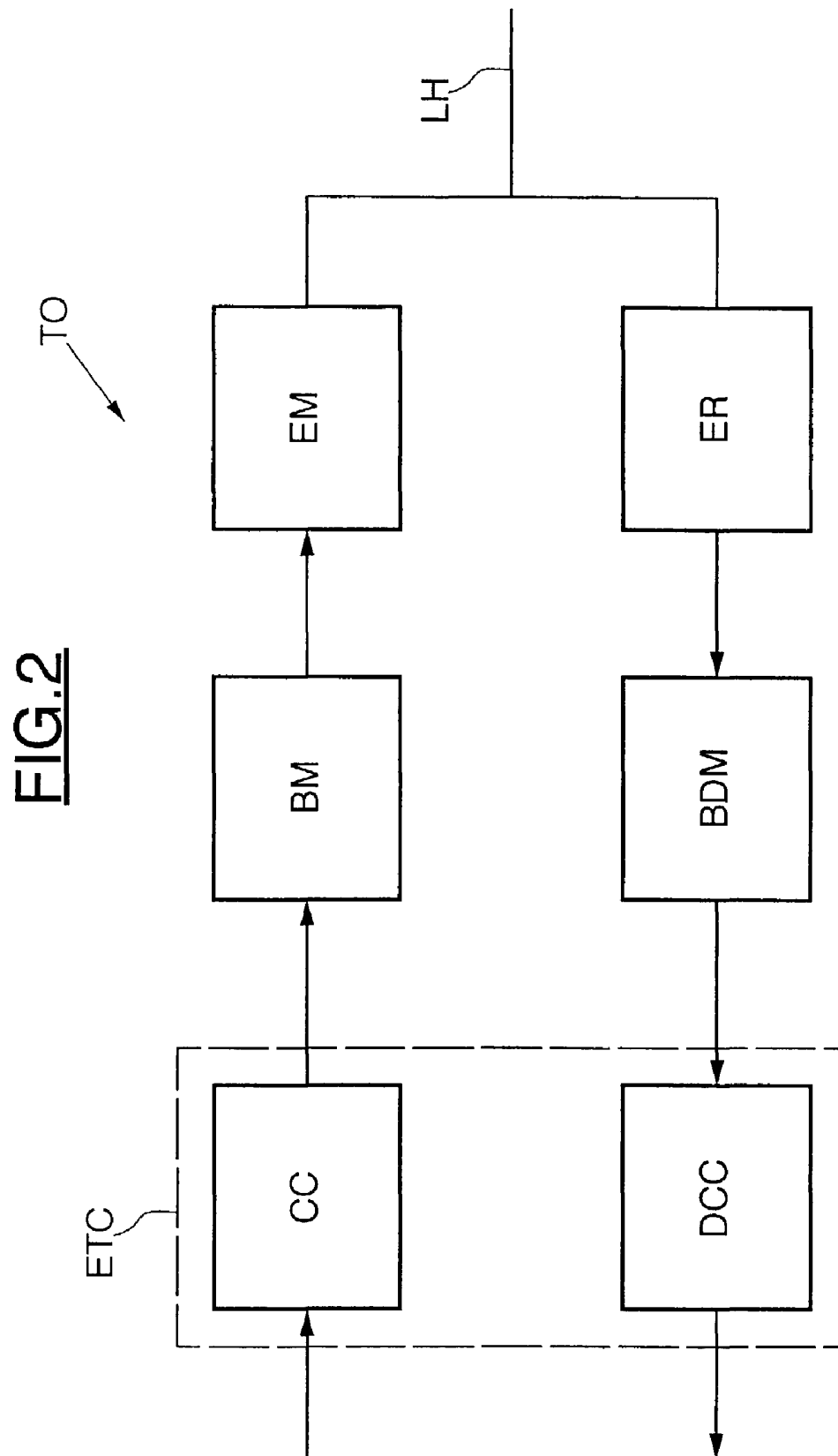


FIG.3

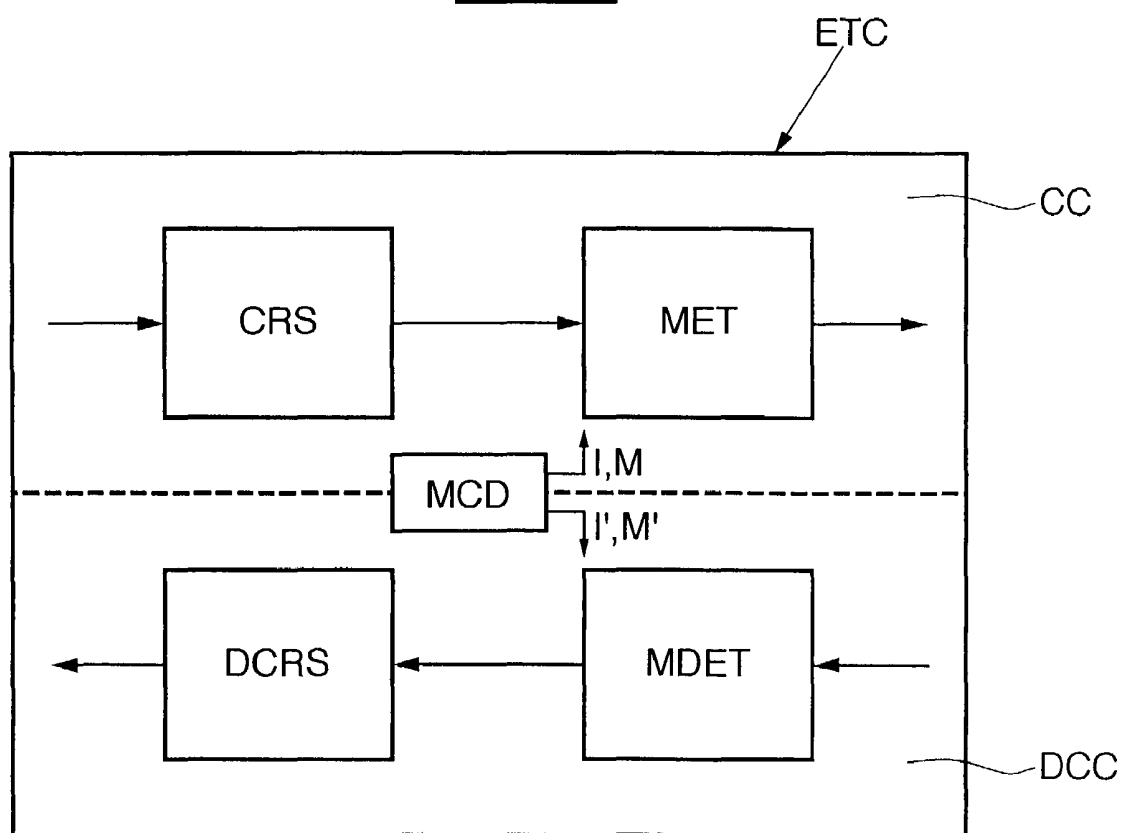


FIG. 5

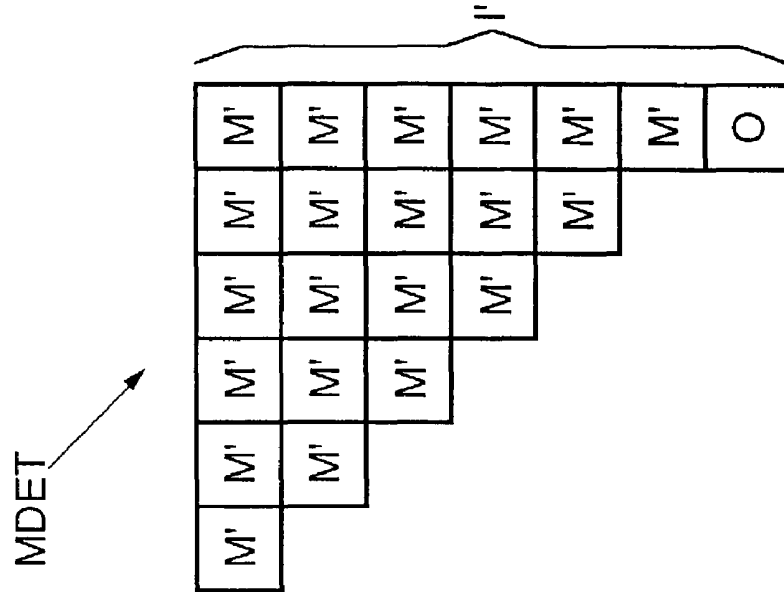


FIG. 4

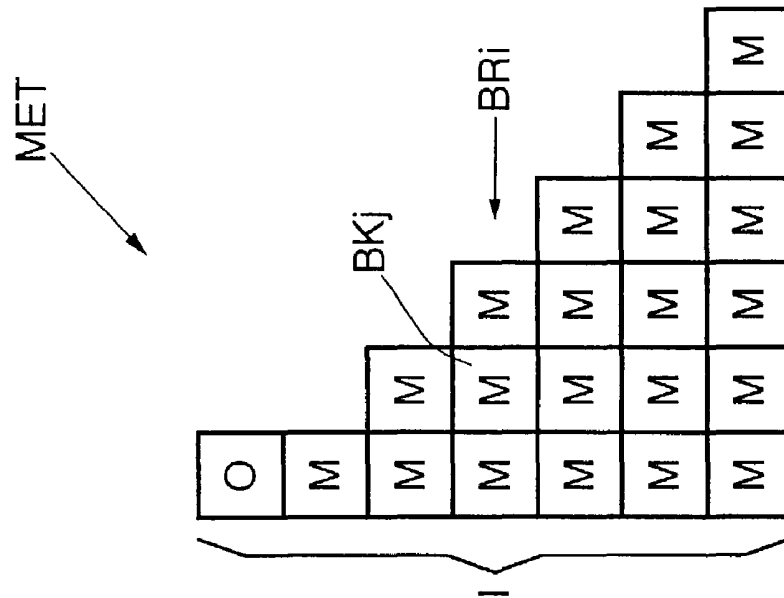


FIG. 6

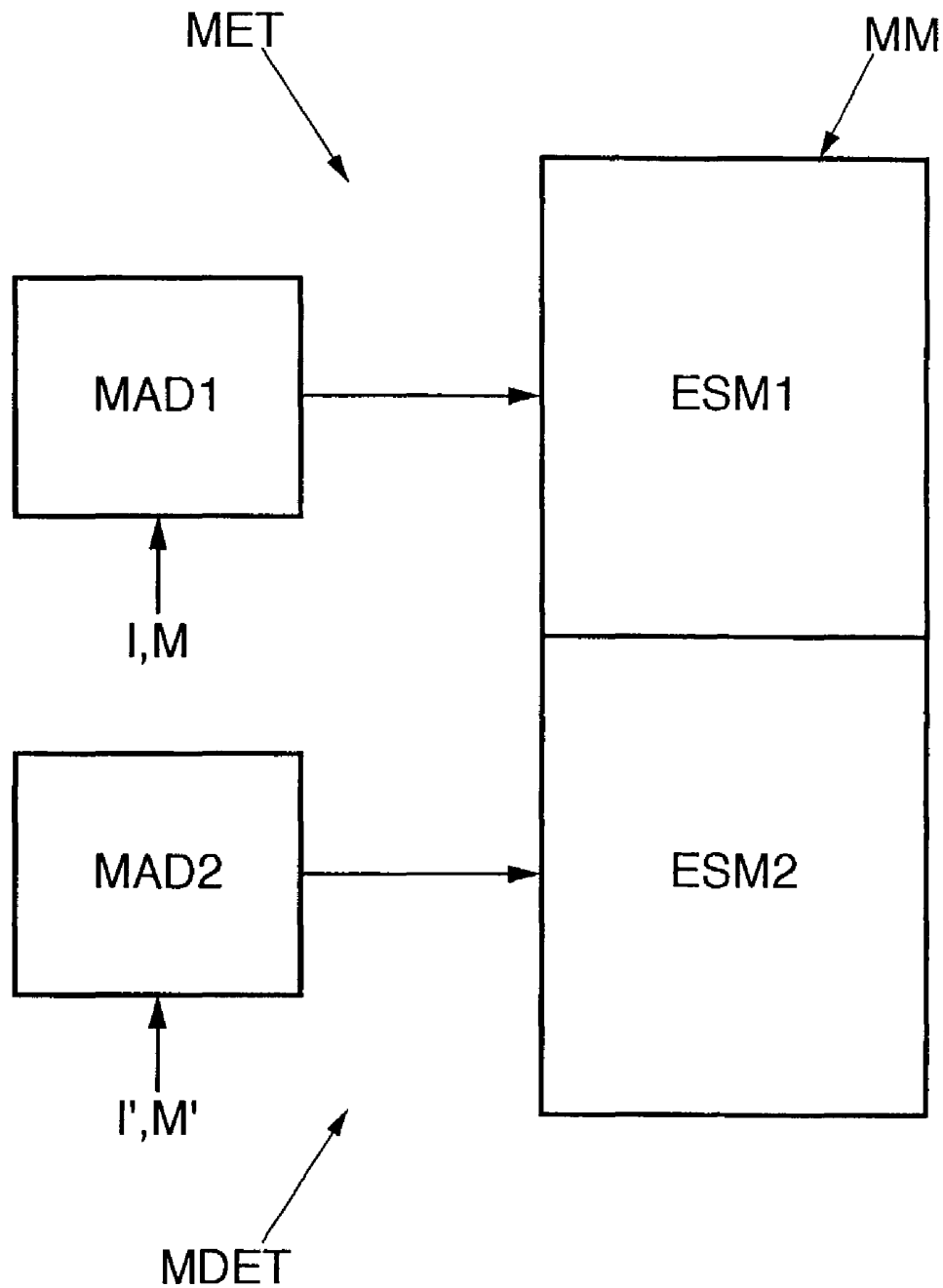


FIG. 7

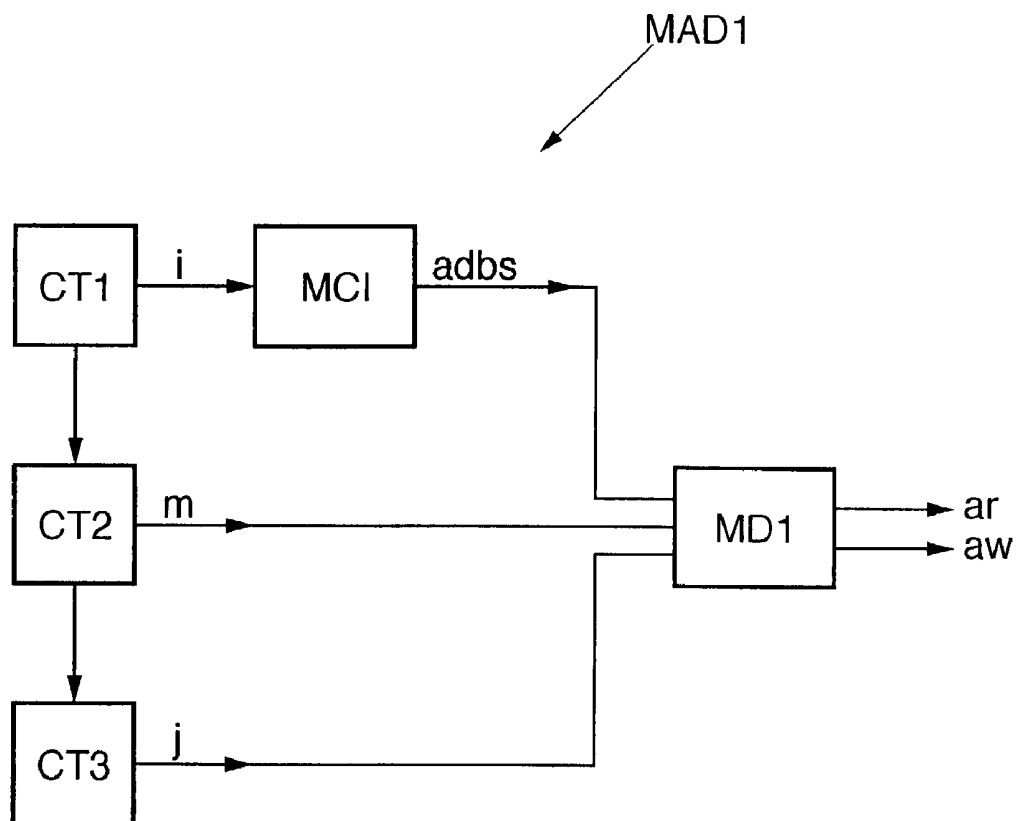
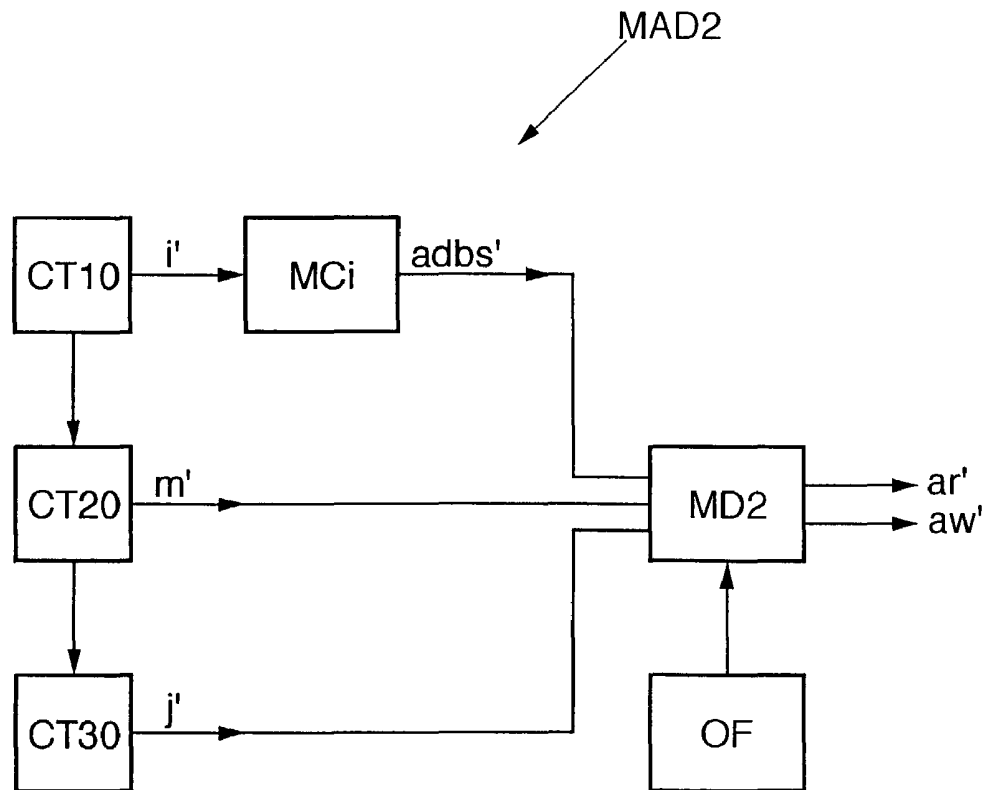


FIG.8



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# **DEVICE FOR SENDING/RECEIVING DIGITAL DATA CAPABLE OF PROCESSING DIFFERENT BIT RATES, IN PARTICULAR IN A VDSL ENVIRONMENT**

## **FIELD OF THE INVENTION**

The present invention relates to the field of telecommunications, and, more particularly, to transmitters and receivers for data communication lines. Moreover, the invention relates to sending and receiving digital data that can have different bit rates, and to choosing the capacity of memory means used by interleaving and deinterleaving processes effected within send/receive devices capable of processing different bit rates.

## **BACKGROUND OF THE INVENTION**

The present invention may advantageously be applied to a very high rate digital subscriber line (VDSL) environment or system, for example, though the invention may also be used in other applications. That is, the invention applies to a digital communication system linking an operator and users via very high bit rate transmission lines. Thus, the invention applies more particularly to send/receive devices, usually referred to as modems, at the operator and user ends of a transmission line.

Those skilled in the art will appreciate that a VDSL communication system is capable of delivering symmetrical services and asymmetrical services. A service is symmetrical if the bit rate of information exchanged between the operator and the user in both transmission directions (i.e., from the operator to the user and from the user to the operator) is exactly the same. A service is asymmetrical if the bit rate of information sent in one transmission direction is different from the bit rate of information sent in the other transmission direction.

The processes of interleaving and deinterleaving data sent and received by a modem necessitates the use of memories. For a modem intended to operate at a predetermined bit rate, the memories must have a capacity that depends on that bit rate.

## **SUMMARY OF THE INVENTION**

An object of the invention is to provide a send/receive device (i.e., modem) architecture which requires a reduced quantity of memory.

Yet another object of the invention is to provide such an architecture which can be used at the operator end or at the user end of a transmission line (i.e., which is fully interchangeable between sending and receiving).

Still another object of the invention is to provide such an architecture which is adaptable, particularly in terms of the memory capacity of the interleaving and deinterleaving means, to suit a number of different bit rates selected from a predetermined group of bit rates.

These and other objects, features, and advantages are provided by a memory means whose size is optimized for a global (send+receive) bit rate, which can be shared between the interleaving means and the deinterleaving means, and whose memory allocation can be reconfigured in accordance with the bit rate actually processed by the send/receive device (modem). The invention therefore provides a device for sending/receiving digital data that is capable of processing different bit rates from a group of predetermined bit rates

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(e.g., all the symmetrical or asymmetrical services offered by the VDSL communication system).

The device according to the invention may include a coding/decoding stage (generally referred to by those skilled in the art as a "channel coding/decoding stage") including interleaving means and deinterleaving means. The interleaving and deinterleaving means include a memory whose minimum size is fixed as a function of the maximum bit rate of the group of predetermined bit rates (e.g., the highest asymmetrical bit rate in the case of a VDSL system). The memory also has a first memory space assigned to the interleaving means and a second memory space assigned to the deinterleaving means. The size of each of the two memory spaces is set as a function of the bit rate actually processed by the device. In the context of the present invention, the term "bit rate" as associated with a memory capacity or memory space is a global bit rate, i.e., the sum of the send and receive bit rates.

It is therefore possible to considerably reduce the size of the memory means required for the interleaving and deinterleaving means implemented within a modem. The modem may be used either at the operator end or at the user end, and it is capable of processing a number of different and symmetrical or asymmetrical bit rates.

The transmitted data stream may be protected from transmission channel noise by a Reed-Solomon coding algorithm, which is well known in the art. To make the Reed-Solomon coding more efficient, the coding means may be coupled to the interleaving means to distribute in time errors introduced by the transmission channel. These errors often occur in bursts and affect several successive bytes, which can reduce the correction capacity of the Reed-Solomon code in isolation (generally eight bytes per packet). The interleaving means may then interleave the bytes temporally by modifying the order in which they are transmitted, which achieves the temporal distribution of the errors.

More specifically, the channel coding/decoding stage may include Reed-Solomon coding/decoding means of length  $N$  (where  $N=240$  bytes, for example). The interleaving means are then adapted to effect convolutional interleaving of  $I$  branches with  $i-1$  blocks of  $N$  bytes. The deinterleaving means are adapted to implement convolutional deinterleaving with  $I'$  branches of  $i'-1$  blocks of  $M'$  bytes.  $I$  and  $I'$  are sub-multiples of  $N$ , and  $i$  and  $i'$  are the current relative indexes of the branches. The size in bytes of the first memory space is equal to  $I \times (i-1) \times M/2$ , and the size in bytes of the second memory space is equal to  $I' \times (i'-1) \times M'/2$ . The sizes of the two memory spaces are set by  $I$ ,  $I'$ ,  $M$  and  $M'$ .

Using convolutional triangular interleaving (and, consequently, convolutional triangular deinterleaving) instead of other conventional types of interleaving is particularly beneficial because it reduces latency generated by the memory. Convolutional triangular interleaving requires a much smaller memory, which reduces latency. Latency is a primordial and decisive criterion for any VDSL communication system.

The memory may be a random access memory, such as a dual-port memory, for example. The interleaving means and the deinterleaving means may respectively include first addressing means and second addressing means. The first and second addressing means may each include a first counter defining the relative index  $i$  or  $i'$  of a branch, and a second counter defining the number of bytes in a block and incremented each time that the first counter reaches its counting limit value. Moreover, the first and second addressing means may also include a third counter defining the current index of a block in the branch with index  $i$  or  $i'$  and

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incremented each time that a block contains M or M' bytes, and intermediate calculation means calculating the address of each branch in the memory from the content of the first counter.

The first addressing means may further include first address determination means adapted to determine successive read and write addresses in the memory of data successively delivered to the interleaving means. The first address determination means determine the addresses from values supplied by the intermediate calculation means, the second and third counters and the parameter M.

The second addressing means may further include second address determination means adapted to determine successive read and write addresses in the memory of data successively delivered to the deinterleaving means. The second address determination means determine the addresses from values supplied by the intermediate calculation means, the second and third counters, the parameter M', and the size of the first memory space. This is so that the first unoccupied address in the memory can be determined.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Other advantages and features of the invention will become apparent upon examining the following detailed description of non-limiting embodiments of the invention and the accompanying drawings, in which:

FIG. 1 is a schematic block diagram of a communication system in accordance with the invention linking two send/receive devices;

FIG. 2 is a more detailed schematic block diagram showing the internal architecture of a send/receive device according to the invention;

FIG. 3 is a schematic block diagram of the internal architecture of a coding/decoding stage of the device shown in FIG. 2;

FIGS. 4 and 5 are schematic diagrams showing the theory of convolutional triangular interleaving and deinterleaving of the present invention;

FIG. 6 is a schematic block diagram of the internal architecture of the interleaving and deinterleaving means of a send/receive device according to the invention;

FIG. 7 is a schematic block diagram of an embodiment of first addressing means associated with the interleaving means; and

FIG. 8 is a schematic block diagram of an embodiment of the second addressing means associated with the deinterleaving means.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An application of the invention to a VDSL communication system will now be described, although the invention is not limited to this application. Referring to FIG. 1, two send/receive devices TO and TU according to the invention are shown, which may be referred to more simply as terminals or modems. One of these terminals, e.g., the terminal TO, is at the operator end. The other terminal TU is at the user end. The two modems are linked by a very high bit rate communication line LH.

The VDSL communication system enables the operator to provide symmetrical services, typically six symmetrical services S1-S6. That is, the information bit rates in the two transmission directions (i.e., from the operator to the user and from the user to the operator) are exactly the same. The service S1 with the lowest bit rate has a bit rate of 32×64

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kbit/s, for example, and the fastest symmetrical service S6 has a bit rate of 362×64 kbit/s.

With the VDSL system, the operator can also provide asymmetrical services A1-A6. These are services with different information bit rates in the user to operator direction (uplink direction) and in the operator to user direction (downlink direction). The first asymmetrical service A1 has a bit rate in the uplink direction of 32×64 kbit/s, for example, and a bit rate in the downlink direction of 100×64 kbit/s. The asymmetrical service having the highest global information bit rate (uplink bit rate+downlink bit rate) is the service A6. The bit rate of the service A6 in the uplink direction is equal to 32×64 kbit/s and in the downlink direction is equal to 832×64 kbit/s.

The send/receive device according to the invention can therefore be installed at the user end or at the operator end and is capable of processing all the above services, as described in more detail hereinafter. Even so, the capacity of the memory assigned to the interleaving/deinterleaving means may need to be chosen in accordance with the maximum bit rate of the services offered, here the bit rate of the highest asymmetrical service (service A6). Furthermore, the parameters of the memory space of that memory may need to be set in accordance with the service actually processed by the device.

The internal architecture of the operator terminal TO from FIG. 1 will now be described in more detail. It should be understood that everything described hereinafter with respect to the operator terminal TO is equally valid for the terminal TU. The terminal TO includes a send system and a receive system both connected to the transmission line LH, as shown in FIG. 2. The terminal TO includes a channel coding/decoding stage ETC including a channel coding unit CC in the send system and a channel decoding unit DCC in the receive system.

The channel coding unit CC includes Reed-Solomon coding means whose structure and function are known to those of skill in the art. The Reed-Solomon coding means are associated with the interleaving means. In conjunction with subsequent interleaving, the Reed-Solomon coding can correct bursts of errors introduced by the transmission channel. Reed-Solomon coding is applied individually to each of the data packets delivered to the input of the coding unit CC.

Reed-Solomon coding adds a number of parity bytes to the bytes of the packets received and can therefore correct a number of erroneous bytes. It is assumed here, by way of example, that the Reed-Solomon code used is an RS (240, 224) code with a correcting power of 8. This notation means that the Reed-Solomon coding means are applied to packets of 224 bytes, to which they add 16 parity bytes, to form a Reed-Solomon coded word whose length is 240 bytes. This makes it possible to correct up to eight erroneous bytes.

Errors introduced by the channel, which often occur in bursts affecting several successive bytes and can therefore exceed the correction capacity of the Reed-Solomon code in isolation, may be distributed temporally. To do so, the bytes are temporally interleaved by modifying the order in which they are transmitted. This improves the efficacy of the Reed-Solomon coding.

The information delivered to the output of the channel coding stage ETC is delivered to a modulation unit BM whose structure is known in the art and which effects quadrature modulation, for example. Then, after various standard processes have been effected in a send unit EM, which includes an interface to the transmission line LH, the modulated signal is transmitted over the transmission line LH.



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Similarly, the receive system of the terminal TO includes at its input a receive unit ER including a receive interface to the transmission line LH which effects standard processing. The modulated signal delivered to the output of the receive unit ER is demodulated in a demodulator unit BDM. The demodulated signal is then delivered to the channel decoding unit DCC. The latter unit includes deinterleaving and Reed-Solomon decoding means.

The internal architecture and the operation of the interleaving and deinterleaving means will now be described in more detail with more particular reference to FIGS. 3-8. As shown in FIG. 3, and as already explained, the interleaving means MET follow the Reed-Solomon coding means CRS, and the deinterleaving means MDET precede the Reed-Solomon decoding means DCRS. As shown diagrammatically in FIGS. 4 and 5, the interleaving and deinterleaving are convolutional triangular interleaving and deinterleaving. There are  $I$  branches of  $i-1$  blocks of  $M$  bytes for interleaving and  $I'$  branches of  $i'-1$  blocks of  $M'$  bytes for deinterleaving.

As explained in more detail hereinafter, the parameters  $I$ ,  $M$ ,  $I'$  and  $M'$  can be modified, e.g., by software, and are delivered by control means MCD (see FIG. 3). The control means MCD may also be implemented in software. These parameters define the sizes of the respective memory spaces assigned to the interleaving means and to the deinterleaving means. This is done according to the bit rate of the information sent by the terminal TO (parameters  $I$  and  $M$ ) and the bit rate of the information received by the terminal TO (parameters  $I'$  and  $M'$ ).

The interleaving means therefore include  $I$  parallel branches  $BR_i$  (numbered from 0 to  $I-1$ , for example) which are implemented with a delay increment of  $M$  per branch ( $M$  represents the maximum number of bytes of a block  $BK_j$  with index  $j$ ). Each branch can be considered as a delay line, the length of the branch with index  $i$  (where  $i$  varies in the range from 0 to  $I-1$ ) being equal to  $i \times M$  bytes. In FIG. 4, by way of example,  $I=7$ .

Accordingly, the first block of  $M$  bytes (having the index 0, for example) is not interleaved and is delivered unmodified to the output of the interleaving means. The next block of  $M$  bytes (index 1) is delivered to the input of the branch  $BR_1$ , and so on up to the seventh block of  $M$  bytes (index 6), which is delivered to the branch  $BR_6$ . The cycle then begins again with the blocks of bytes with indices from 7 to 13. The preceding blocks of bytes are either delivered to the output of the interleaving means or moved forward by one block  $BK_j$  in the branch concerned.

The deinterleaving means associated with the interleaving means MET, and which are consequently incorporated into the user terminal TU, have a structure analogous to that which has just been described for the interleaving means. Yet, the indices of the branches are reversed so that the longest interleaving time-delay corresponds to the shortest deinterleaving time-delay. The deinterleaving means MDET incorporated in the operator terminal TO have  $I'$  branches, the branch with index  $i'$  having a length equal to  $i' \times M'$  bytes.

For simplicity, the situation in which  $I'=I$  is shown in FIG. 5. However, if the service is an asymmetrical service,  $I$  and  $I'$  are generally different, of course, and likewise  $M$  and  $M'$ . In hardware terms, as shown diagrammatically in FIG. 6, the interleaving means and the deinterleaving means include common memory means MM, e.g., a dual-port random access memory. The memory space of the memory MM is then divided into a first memory space ESM1 assigned to the interleaving means MET, and a second memory space ESM2 is assigned to the deinterleaving means MDET.

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The interleaving means also include first addressing means MAD1 receiving the parameters  $I$  and  $M$ . The deinterleaving means also include second addressing means MAD2 receiving the parameters  $I'$  and  $M'$ . The structure of the addressing means is described in more detail hereinafter with reference to FIGS. 7 and 8. The minimum size of the memory MM is set by the maximum bit rate that the send/receive device can process. The maximum bit rate is, of course, the sum of the uplink bit rate and the downlink bit rate.

In this example, the maximum bit rate is that of the largest asymmetrical service A6. An example of the capacity of the memory MM and of the values chosen for the parameters  $I$ ,  $M$ ,  $I'$  and  $M'$  for an asymmetrical service A6 and an RS (240, 224) Reed-Solomon code with a correction power of 8 bytes/word may be as follows when the transmission lines are disturbed by an impulsive noise with a duration of 0.25 ms.

In the downlink direction, the maximum bit rate is equal to 832x64 kbit/s. The number of bits affected by noise is consequently equal to the product of that bit rate by the duration of the impulsive noise, which yields a number of bits affected by noise equal to 13,312 (1,664 bytes). Given the correcting power of the Reed-Solomon code (here 8), the number  $nrs$  of Reed-Solomon words needed to correct 1,664 bytes subject to noise is equal to 1,664/8, i.e. 208. The size of the memory space needed to store this maximum bit rate is then equal to  $N \times nrs/2$ , where  $N$  is the size of the Reed-Solomon code (here 240). The resulting memory space size is therefore equal to 24,960 bytes.

The bit rate in the uplink direction is equal to 32x64 kbit/s. A similar calculation shows that the number of bits affected by noise is equal to 512, and that  $nrs=8$ . The memory size to be provided for the uplink direction is therefore equal to 1,920 bytes. The minimum size of the memory MM is therefore 26,880 bytes.

The parameters  $I$ ,  $I'$ ,  $M$  and  $M'$  can be determined from the above capacities. More particularly, the size of the first memory space needed to implement triangular convolutional interleaving with  $I$  branches of  $i-1$  blocks of  $M$  bytes is equal to  $I \times (I-1) \times M/2$ . Similarly, the size of the second memory space ESM2 required to support the uplink bit rate is equal to  $I' \times (I'-1) \times M'/2$ . Also,  $I$  and  $I'$  must be sub-multiples of the size  $N$  of the Reed-Solomon code.

Since  $I \times (I-1) \times M/2$  must be equal to 24,960, it is possible to choose  $I=40$  and  $M=32$ . Similarly, because  $I' \times (I'-1) \times M'/2$  must be at least equal to 1,920, it is possible to choose  $I'=24$  and  $M'=7$ . This requires a slight increase in size to 1,932 to facilitate the implementation. The final size of the memory MM is therefore equal to 26 892 bytes.

The above calculation of  $I$ ,  $M$ ,  $I'$  and  $M'$  for the asymmetrical service A6 can be applied in an analogous manner to the other services of the VDSL system. A table of values for the parameters  $I$ ,  $M$ ,  $I'$  and  $M'$  can therefore be stored in the coding/decoding stage. When the modem is installed at the end of the line, and depending on the service actually provided by the operator, the control means MCD may retrieve the corresponding values of  $I$ ,  $M$ ,  $I'$  and  $M'$  from the stored table. These values are delivered to the addressing means MAD1 and MAD2, the structure of which is described in more detail with reference to FIGS. 7 and 8.

As shown in FIG. 7, the first addressing means include a first counter CT1 delivering the relative index  $i$  of a branch  $BR_i$  at the timing rate of a clock signal. The index  $i$  is delivered to intermediate calculation means MCI that determine the address  $adbs$  of the branch  $BR_i$  in the first memory space. More specifically, the address  $adbs$  is equal to  $i \times (i-$

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1)/2. The means MCI can be easily implemented using multipliers, dividers and subtractors.

The first counter CTI has a counting range equal to I and therefore counts from 0 to I-1, for example. The means MD1 further include a second counter CT2 which delivers a current value m equal to the current number of bytes in each block BK<sub>j</sub> of a branch BR<sub>i</sub>. The counting range of the counter CT2 is equal to M. In other words, m can vary from 0 to M-1, for example. The second counter CT2 is incremented by one unit each time that i=i-1.

The means MDA1 further include a third counter CT3 which delivers the index j of the block BK<sub>j</sub> within the branch with index i. The counting range of the counter CT3 is equal to i. In other words, j varies from 0 to i-1, for example. The third counter CT3 is incremented each time that a block contains M bytes, and therefore in this example each time that the counter CT2 reaches the value M.

The means MDA1 further include first address determination means MD1 which determine the read address ar in the memory and the write address aw in the memory. More precisely, the read address ar is equal to (adbs+j)×M+m. The write address aw is then simply equal to the read address but delayed by one cycle of the clock signal. Again, the means MD1 can be easily implemented using adders and multipliers.

For example, a small auxiliary dual-port memory with a capacity of (I-1)×M bits can be used to store the value of the index j delivered by the third counter CT3, which is incremented every M clock cycles. Every M clock cycles, the value of j corresponds to the i<sup>th</sup> branch in the auxiliary memory, after which the counter CT3 is incremented and the new value is rewritten at the same address.

The second addressing means MDA2 that deliver the read address ar' and the write address aw' in the second memory space of the memory MM have a structure similar to that just described for the first addressing means MDA1. Only the differences between the means MDA1 and the means MDA2 are described herein. The first counter CT10 delivers the relative index i' of a branch. This time i' varies in the range of I'-1 to 0. The intermediate calculation means MCI deliver the address of each branch adbs' using a formula analogous to that used to calculate the address, but substituting i' for i.

The second counter CT20 defines the number m' of bytes in a block and is incremented each time that the counter CT10 reaches its counting limit value, in this example when i' reaches the value 0. In this example, the second counter CT20 varies in the range from 0 to M'-1. The third counter CT30 defines the current index j' of a block in the branch with index i'. It varies in the range from 0 to i'-1 and is incremented each time that a block contains M' bytes, i.e., when the second counter CT20 reaches the value M'.

The second addressing means MDA2 include second address determination means MD2 which determine the write address aw' and the read address ar'. However, the second address determination means MD2 must allow for the size OF of the first memory space ESM1, which is defined by equation (1) below:

$$OF = I \times (I-1) \times M/2, \quad (1)$$

and may be stored in a register, for example. For uplink interleaving, the addresses of the memory MM vary in the range of 0 to OF-1.

The first unoccupied address in the memory MM therefore has the value OF. The means MD2 then calculate the read address ar' from equation (2) below:

$$ar' = OF + M' \times (adbs' + j') + m'. \quad (2)$$

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The write address aw' is equal to the read address and is available on the next clock pulse.

Of course, everything just described here for the terminal TO applies to the terminal TU with deinterleaving means with I branches and interleaving means with I' branches. For the user terminal TU it is then necessary to substitute I' for I, and vice versa, and M' for M, and vice versa, in the foregoing description. It would equally be possible to use a single-port memory in place of a dual-port memory by adopting a clock signal having twice the frequency.

That which is claimed is:

1. A device for sending and receiving digital data that is capable of processing different bit rates from a group of predetermined bit rates, the device comprising:

a channel coding/decoding stage comprising

an interleaver,

a deinterleaver,

a shared memory having a minimum size based upon a maximum bit rate of the group of predetermined bit rates and having a first memory space assigned to said interleaver and a second memory space assigned to said deinterleaver, a size of each of the first and second memory spaces being set as a function of the bit rate actually processed by the device,

a Reed-Solomon coder/decoder connected to said interleaver and said deinterleaver and having a length N, and

said interleaver providing convolutional interleaving of I branches with i-1 blocks of M bytes, and said deinterleaver providing convolutional deinterleaving with I' branches of i'-1 blocks of M' bytes, with I and I' being sub-multiples of N and i and i' being current relative indexes of the branches.

2. The device according to claim 1 wherein the size of the first memory space is equal to I×(I-1)×M/2 bytes, the size of the second memory space is equal to I'×(I'-1)×M'/2 bytes, and the sizes of the first and second memory spaces are set by I, I', M and M'.

3. The device according to claim 1 wherein said interleaver and said deinterleaver respectively comprise a first addressing device and a second addressing device, said first and second addressing devices each comprising:

a first counter defining the relative index i or i' of a branch and having a counting limit value;

a second counter defining a number of bytes in a block and incremented each time that said first counter reaches its counting limit value;

a third counter defining the current index of a block in the branch with index i or i' to be incremented each time the block in the branch with index i or i' has M or M' bytes; and

an intermediate calculation device for calculating the address of each branch in said memory from the content of said first counter.

4. The device according to claim 3 wherein said first addressing device further comprises a first address determination device for determining successive read and write addresses in said memory of data successively delivered to said interleaver and said first address determination device, the successive read and write addresses being determined based upon values supplied by said intermediate calculation device, said second and third counters, and the parameter M.

5. The device according to claim 3 wherein said second addressing device further comprises a second address determination device for determining successive read and write addresses in said memory of data successively delivered to said deinterleaver and said second address determination

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device, the successive read and write addresses being determined based upon values supplied by said intermediate calculation device, said second and third counters, the parameter  $M'$ , and the size of the first memory space.

6. The device according to claim 1 wherein said memory comprises a random access memory.

7. The device according to claim 1 wherein said memory comprises a dual-port memory.

8. A device for sending and receiving digital data that is capable of processing different bit rates from a group of predetermined bit rates, the device comprising:

- a channel coding/decoding stage comprising
  - an interleaver,
  - a deinterleaver,
  - a shared random access memory whose minimum size is fixed as a function of a maximum bit rate of the group of predetermined bits and having a first memory space assigned to said interleaver and a second memory space assigned to said deinterleaver, a size of each of the first and second memory spaces being set as a function of the bit rate actually processed by the device, and
- a Reed-Solomon coder/decoder connected to said interleaver and said deinterleaver and having a length  $N$ , said interleaver providing convolutional interleaving of  $I$  branches with  $i-1$  blocks of  $M$  bytes, and said deinterleaver providing convolutional deinterleaving with  $I'$  branches of  $i'-1$  blocks of  $M'$  bytes, with  $I$  and  $I'$  being sub-multiples of  $N$  and  $i$  and  $i'$  being current relative indexes of the branches, said interleaver and said deinterleaver respectively comprising a first addressing device and a second addressing device, said first and second addressing devices each comprising
  - a first counter defining the relative index  $i$  or  $i'$  of a branch and having a counting limit value,
  - a second counter defining a number of bytes in a block and incremented each time that said first counter reaches its counting limit value,
  - a third counter defining the current index of a block in the branch with index  $i$  or  $i'$  to be incremented each time the block in the branch with index  $i$  or  $i'$  has  $M$  or  $M'$  bytes, and
  - an intermediate calculation device for calculating the address of each branch in said random access memory from the content of said first counter.

9. The device according to claim 8 wherein the size of the first memory space is equal to  $I \times (I-1) \times M/2$  bytes, the size of the second memory space is equal to  $I' \times (I'-1) \times M'/2$  bytes, and the sizes of the first and second memory spaces are set by  $I$ ,  $I'$ ,  $M$  and  $M'$ .

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10. The device according to claim 8 wherein said first addressing device further comprises a first address determination device for determining successive read and write addresses in said random access memory of data successively delivered to said interleaver and said first address determination device, the successive read and write addresses being determined based upon values supplied by said intermediate calculation device, said second and third counters, and the parameter  $M$ .

11. The device according to claim 8 wherein said second addressing device further comprises a second address determination device for determining successive read and write addresses in said random access memory of data successively delivered to said deinterleaver and said second address determination device, the successive read and write addresses being determined based upon values supplied by said intermediate calculation device, said second and third counters, the parameter  $M'$ , and the size of the first memory space.

12. The device according to claim 8 wherein said random access memory comprises a dual-port memory.

13. A method for sending and receiving digital data and processing different bit rates from a group of predetermined bit rates, the method comprising:

- interleaving and deinterleaving the digital data;
- setting a minimum size of a shared memory based upon a maximum bit rate of the group of predetermined bit rates;
- assigning a first memory space of the shared memory for interleaving and a second memory space of the shared memory for deinterleaving, a size of each of the first and second memory spaces being set as a function of the bit rate actually processed by the device;
- performing Reed-Solomon coding and decoding for a length  $N$  of the digital data; and
- the interleaving providing convolutional interleaving of  $I$  branches with  $i-1$  blocks of  $M$  bytes, and the deinterleaving providing convolutional deinterleaving with  $I'$  branches of  $i'-1$  blocks of  $M'$  bytes, with  $I$  and  $I'$  being sub-multiples of  $N$  and  $i$  and  $i'$  being current relative indexes of the branches.

14. The method according to claim 13 wherein the size of the first memory space is equal to  $I \times (I-1) \times M/2$  bytes, the size of the second memory space is equal to  $I' \times (I'-1) \times M'/2$  bytes, and the sizes of the first and second memory spaces are set by  $I$ ,  $I'$ ,  $M$  and  $M'$ .

15. The method according to claim 13 wherein the memory comprises a random access memory.

\* \* \* \* \*

UNITED STATES PATENT AND TRADEMARK OFFICE  
**CERTIFICATE OF CORRECTION**

PATENT NO. : 7,269,208 B2  
APPLICATION NO. : 10/088387  
DATED : September 11, 2007  
INVENTOR(S) : Mazzoni et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 2, Line 41

Delete: "N"  
Insert: -- M --

Column 10, Line 44

Delete: " $I \times (I' - 1) \times M/2$ "  
Insert: --  $I \times (I - 1) \times M/2$  --

Signed and Sealed this

Twentieth Day of May, 2008

A handwritten signature in black ink, appearing to read "Jon W. Dudas". The signature is stylized with a large, looped initial "J" and a distinct "D".

JON W. DUDAS  
*Director of the United States Patent and Trademark Office*

# **EXHIBIT 16**

US005751741A

**United States Patent** [19]

Voith et al.

[11] **Patent Number:** 5,751,741[45] **Date of Patent:** May 12, 1998[54] **RATE-ADAPTED COMMUNICATION SYSTEM AND METHOD FOR EFFICIENT BUFFER UTILIZATION THEREOF**[75] **Inventors:** Raymond Paul Voith; Sujit Sudhaman; George Hoekstra, all of Austin, Tex.[73] **Assignee:** Motorola, Inc., Schaumburg, Ill.[21] **Appl. No.:** 754,768[22] **Filed:** Nov. 20, 1996[51] **Int. Cl.<sup>6</sup>** ..... H03M 13/22[52] **U.S. Cl.** ..... 371/37.7; 370/914; 371/2.2; 371/37.02[58] **Field of Search** ..... 371/37.02, 2.2, 371/37.7; 370/914[56] **References Cited****U.S. PATENT DOCUMENTS**

5,596,604	1/1997	Cioffi et al.	345/260
5,636,224	6/1997	Voith et al.	371/2.1

**OTHER PUBLICATIONS**

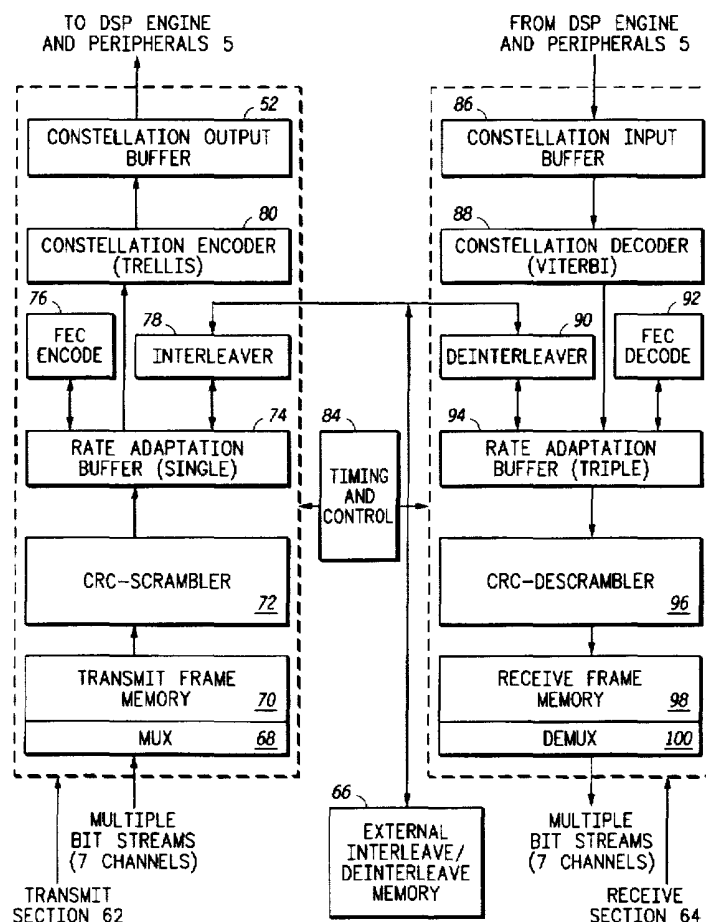
American Nat'l. Standards Institute, Inc., "Asymmetric Digital Subscriber Line (ADSL) Metallic Interface", American Nat'l. Standards Inst. Inc., Network and Customer Installation Interfaces, pp. 1-170.

*Primary Examiner*—Stephen M. Baker

*Attorney, Agent, or Firm*—Daniel D. Hill; Paul J. Polansky

[57] **ABSTRACT**

A transceiver (34) includes a rate adaptation buffer (74) that synchronizes a data stream received at a 4.0 kHz rate to a data stream that is transmitted at a 4.05 kHz rate. A transmit section (62) of the transceiver (34) performs rate adaptation using a single rate adaptation buffer. The transmit section (62) includes four autonomous modules which are able to access the data in the rate adaptation buffer (74) independently of one another. These four modules include a CRC-scrambler (72), a FEC encoder (76), an interleaver (78), and a constellation encoder (80). A timing controller (84) prevents contention for accesses to the rate adaptation buffer (74). In addition, each of the four modules perform their respective functions quickly enough to prevent overflow or underflow conditions in the rate adaptation buffer (74). A receive section (64) functions similarly to the transmit section (62).

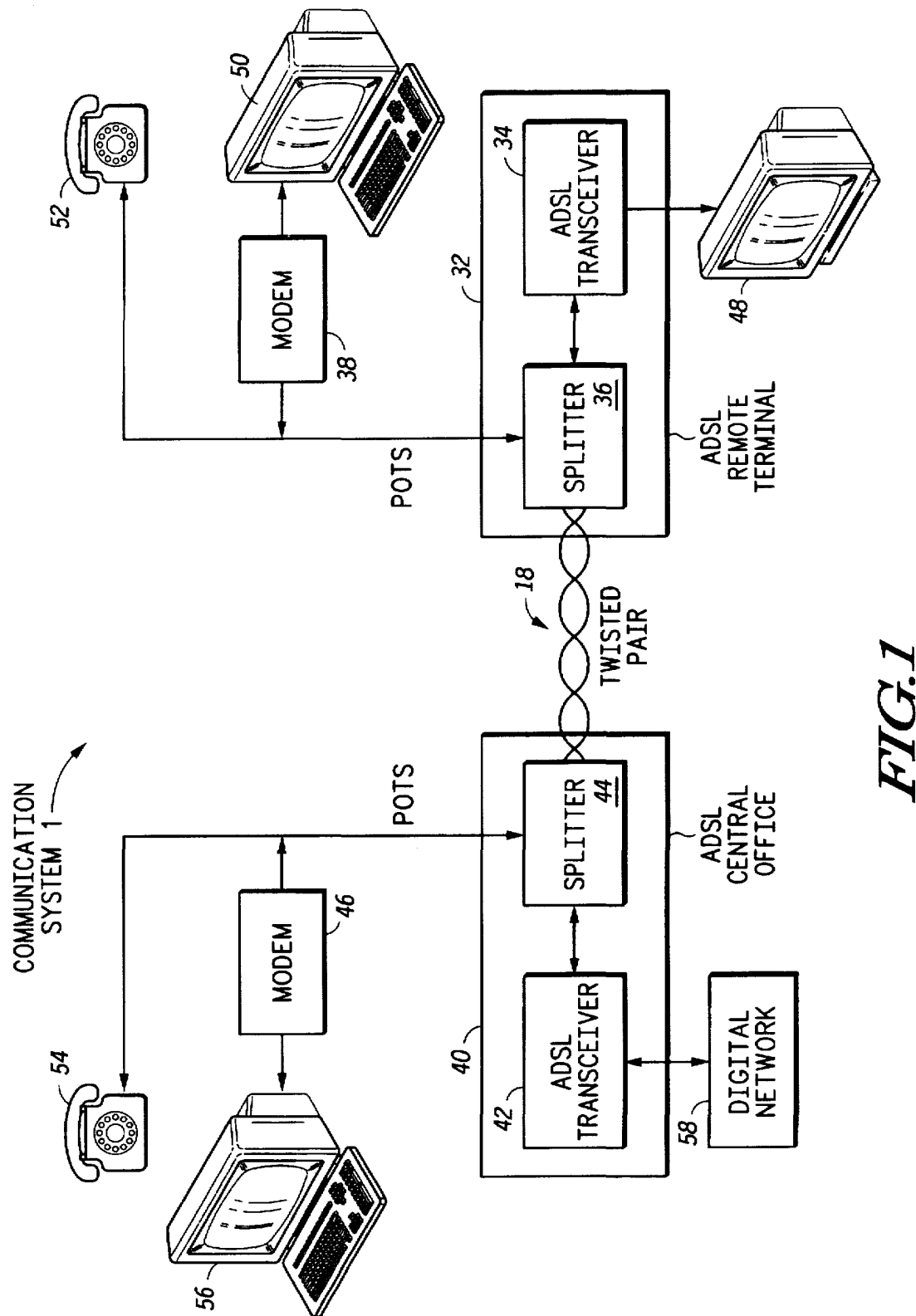
**18 Claims, 6 Drawing Sheets**

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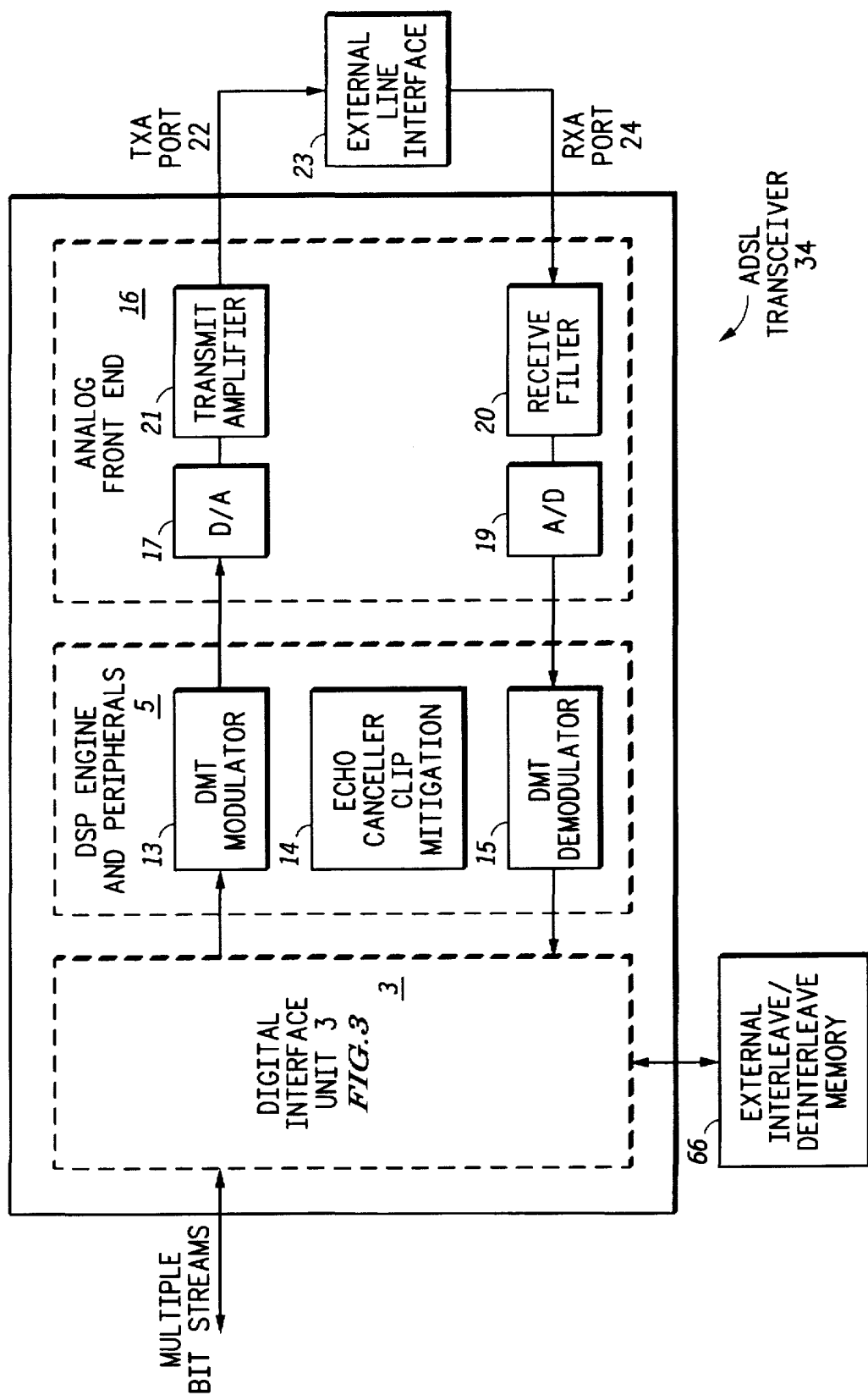


FIG. 2



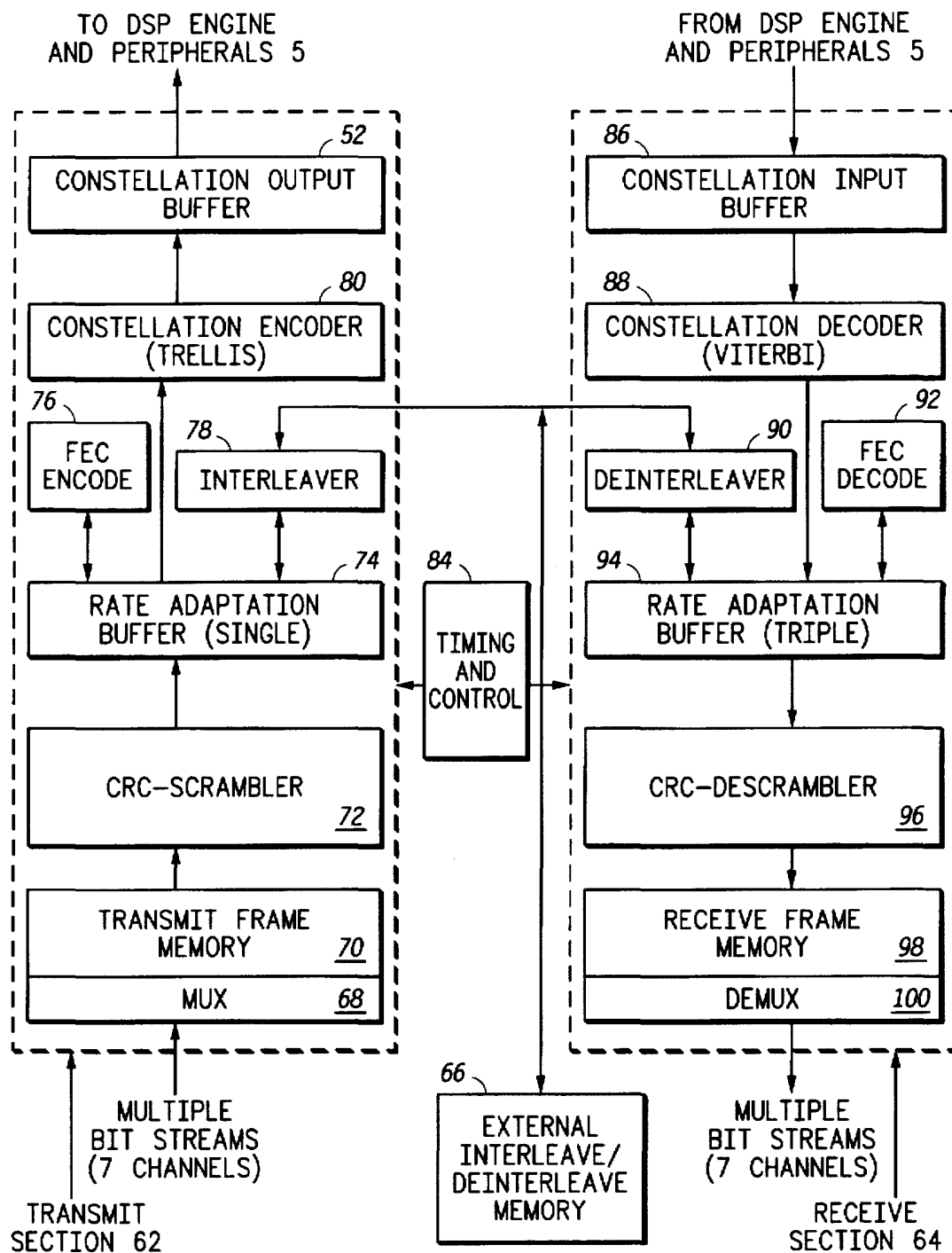


FIG. 3

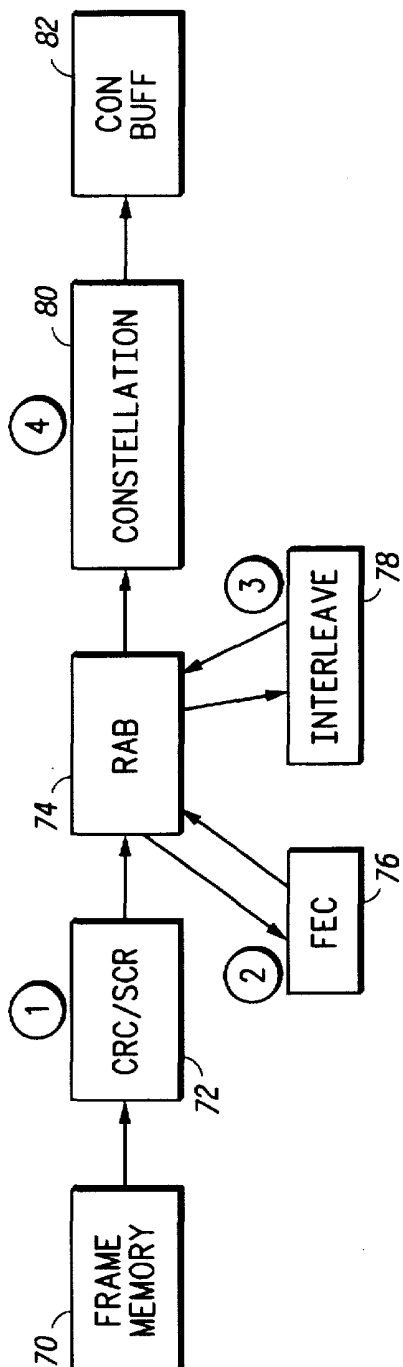


FIG. 4

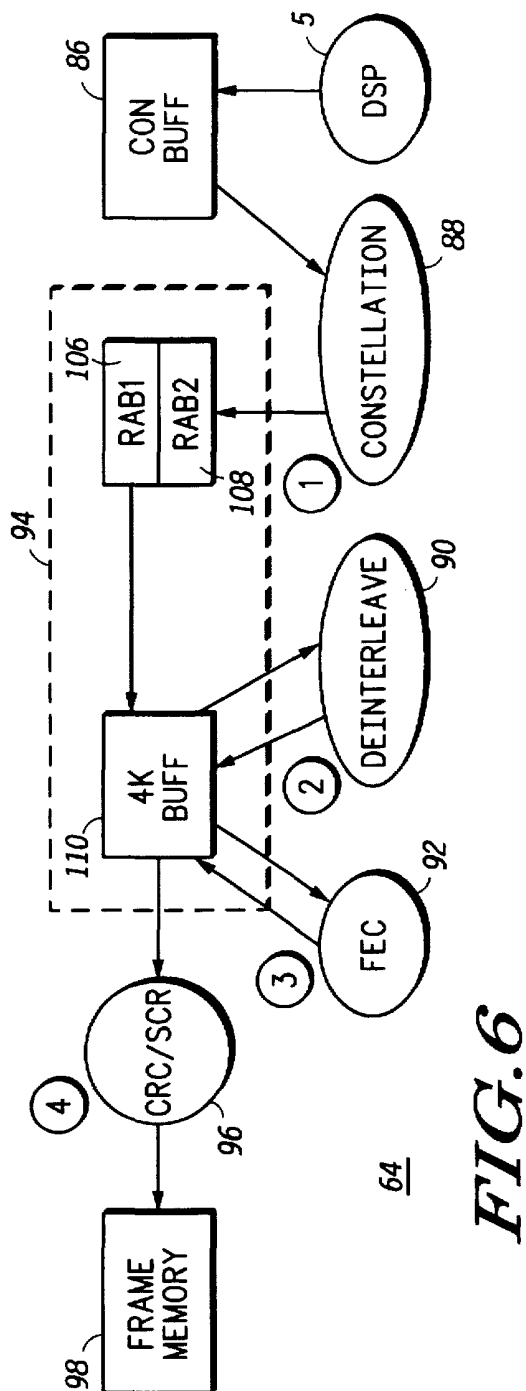


FIG. 6

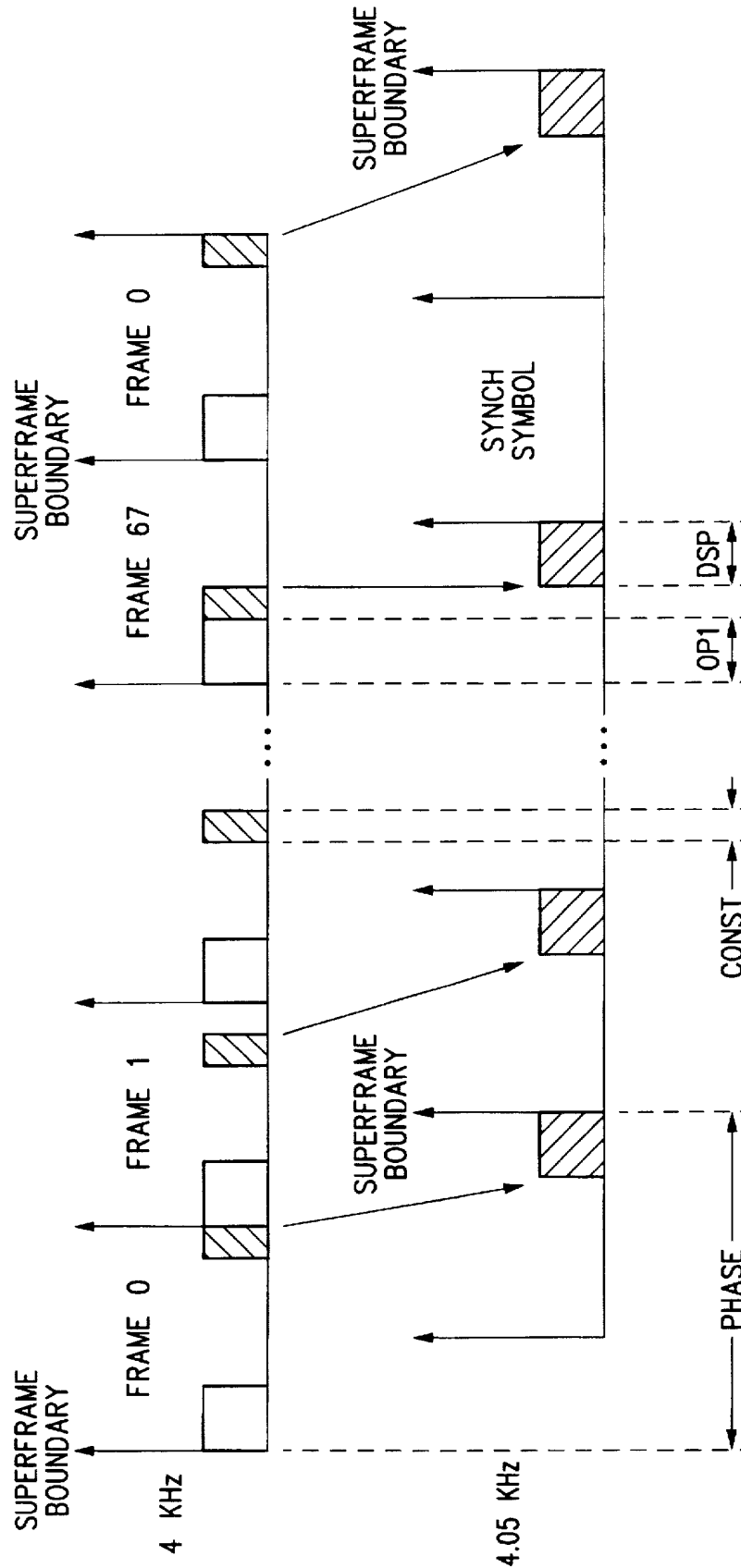


FIG. 5

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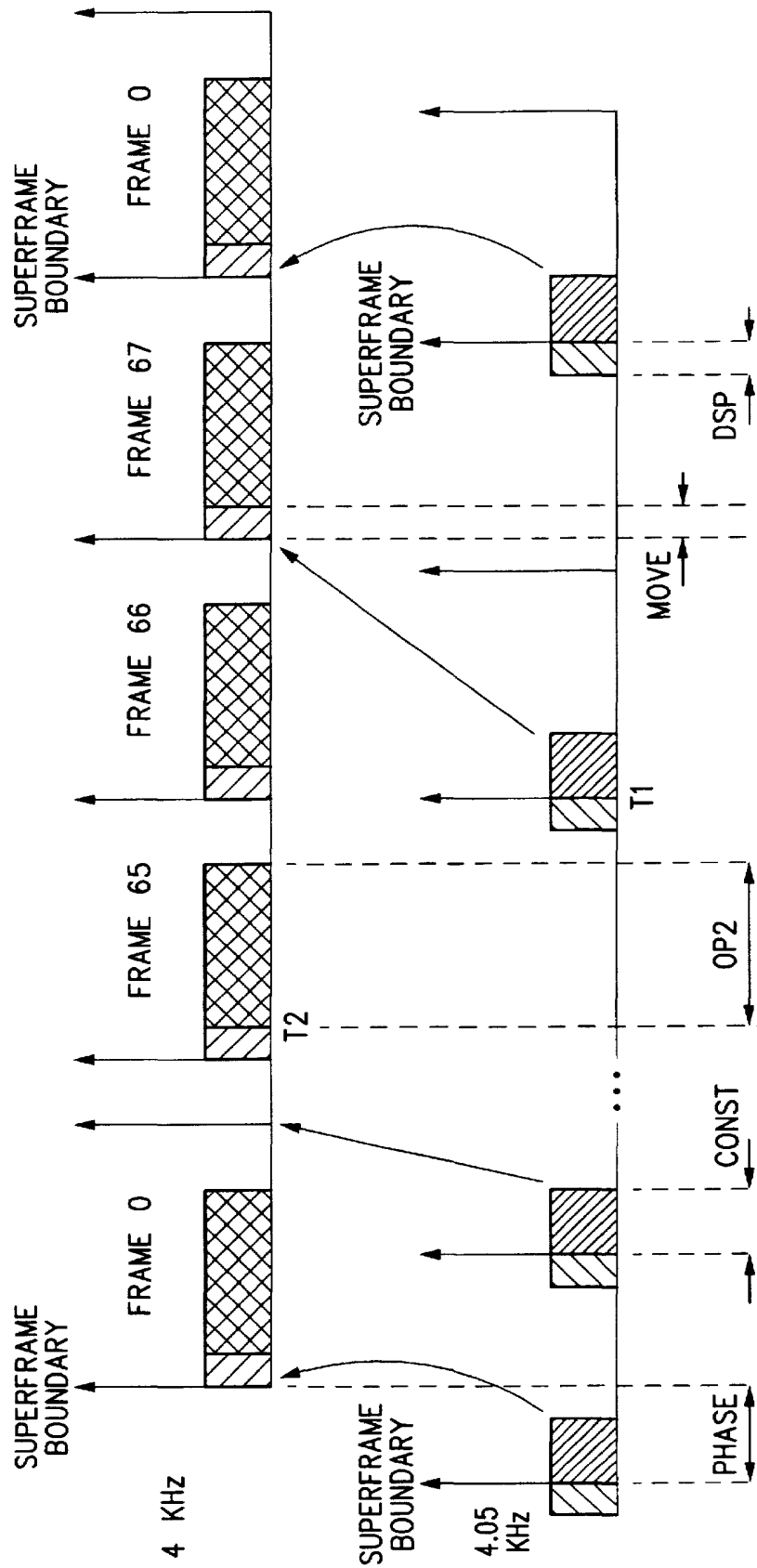


FIG. 7

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# **RATE-ADAPTED COMMUNICATION SYSTEM AND METHOD FOR EFFICIENT BUFFER UTILIZATION THEREOF**

## **FIELD OF THE INVENTION**

This invention relates generally to communications, and more particularly, to communications systems requiring rate adaptation.

## **BACKGROUND OF THE INVENTION**

As the complexity of communication systems increases, there is more and more need for additional ways of transmitting information. One method of communication is called Asymmetrical Digital Subscriber Line (ADSL) and is a transmission scheme that allows for the provision of plain old telephone service (POTS) and a variety of digital channels on two wire twisted metallic wire pair with mixed gauges. It is desirable to use such twisted pair wire as there is an existing infrastructure, the use of which will reduce installation costs. ADSL standards are proposed in the draft American National Standard for Telecommunication—Network and Customer Interfaces—Asymmetric Digital Subscriber Line (ADSL) metallic interface, T1E1.4/95-007R2, ADSL coding standard, draft, Aug. 15, 1995.

Discrete multi-tone (DMT) is a multi-carrier technique which divides the available bandwidth of twisted-pair copper media connections into mini-subchannels or bins. The DMT technique has been proposed for adoption by the ANSI T1E1.4 (ADSL) committee to be used in ADSL communications systems. In the proposed ADSL standard, T1E1.4 DMT is used to generate 250 separate 4.3125 kilohertz (kHz) subchannels from 26 kilohertz to 1.1 megahertz (MHz) for downstream transmission to an end user. Likewise, DMT is used to generate 26 subchannels from 26 kilohertz to 138 kilohertz for upstream transmission by an end user. The asymmetric transmission protocol implemented by the proposed ADSL standard requires a higher rate of data transmission from a central office to a remote terminal and a lower rate of data transmission from a remote terminal to a central office. As a result, different processing sequences are required at the remote terminal and central office ends.

One of the advantages of ADSL transmission is that it may be used to provide high quality, multiple and simultaneous interactive video services over an ordinary telephone line without disruption of the standard telephone service.

In ADSL, data may be received from (and provided to) several channels and the data is grouped into structures known as frames. Each frame includes both payload data bytes and overhead bytes. Data from each channel is placed in different positions in the frame depending on whether it is interleaved or non-interleaved. In general, for transmission, the ADSL equipment must assemble the payload data from the channels into a frame and append the overhead bytes as appropriate. In particular, the ADSL equipment must perform a cyclic redundancy check (CRC), scramble, interleave (if selected), and perform forward error correction coding (FEC) on frame data. Once the transmit data and overhead bytes are assembled into a frame, the ADSL equipment must convert the frame data into a set of complex symbols. Each symbol represents a number of frame bits as defined by a bit allocation table. These complex symbols are subsequently converted into an analog signal transmitted on the telephone line. Conversely, when receiving an analog signal from the telephone line, the ADSL equipment must convert the analog signal into complex

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digital symbols, convert the complex symbols into a receive frame, and perform deinterleaving, FEC, CRC, and descrambling to convert the received frame into recovered payload data.

The frames in turn are grouped together into a "super-frame" which includes 68 data frames plus an additional synchronization frame. CRC calculation is performed on all the data in the 68 data frames of a superframe, and the CRC calculated for a prior superframe is transmitted in the overhead bytes of the first frame of the next superframe. The synchronization frame is a special frame which the ADSL equipment uses to delineate the boundary of a superframe.

The existence of the synchronization frame creates a rate adaptation problem with the ADSL equipment. On the transmit side, 68 frames of transmit data are gathered in 17 milliseconds (ms), but symbols corresponding to 69 frames (68 frames plus the synchronization frame) are transmitted on the telephone line in the same amount of time. Similarly on the receive side, symbols corresponding to 69 frames of receive data (68 frames plus the synchronization frame) are received from the telephone line in 17 microseconds but only 68 frames are processed in the same amount of time. One way of solving this problem is to add a large buffer area so that while the supplier of data is filling one part of the buffer from one side, the consumer of data is emptying another part of buffer from the other side. However, large buffers consume a large integrated circuit area which adds to its cost. Another problem is that the ADSL equipment must perform all the functions required quickly enough to avoid overflow and underflow conditions. The present invention overcomes these problems by providing an efficient ADSL apparatus, whose features and advantages will be more clearly understood by reference to the Detailed Description in conjunction with the accompanying drawings.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 illustrates, in block diagram form, an asymmetrical digital subscriber line (ADSL) communication system in accordance with one embodiment of the present invention.

FIG. 2 illustrates, in block diagram form, the ADSL transceiver of FIG. 1.

FIG. 3 illustrates, in block diagram form, the digital interface of FIG. 2.

FIG. 4 illustrates, in block diagram form, the signal processing operations performed on the transmit rate adaptation buffer of FIG. 3.

FIG. 5 illustrates a timing diagram of the signal processing operations performed on the transmit rate adaptation buffer of FIG. 3.

FIG. 6 illustrates, in block diagram form, the signal processing operations performed on the receive rate adaptation buffer of FIG. 3.

FIG. 7 illustrates a timing diagram of the signal processing operations performed on the receive rate adaptation buffer of FIG. 3.

## **DESCRIPTION OF A PREFERRED EMBODIMENT**

Generally, the present invention provides an ADSL transceiver having a rate adaptation buffer that synchronizes a data stream received at a 4.0 kHz rate to a data stream that is transmitted at a 4.05 kHz rate. A transmit section of the transceiver is able to perform this rate adaptation using a single rate adaptation buffer, without the need for multiple frame buffering as in known rate adaptation techniques. The

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transmit section includes four autonomous modules which are able to access the data in the rate adaptation buffer independently of one another. These four modules include a CRC-scrambler, a FEC encoder, an interleaver, and a constellation encoder. Timing control prevents contention for accesses to the rate adaptation buffer. In addition, each of the four modules perform their respective functions quickly enough to prevent overflow or underflow conditions in the rate adaptation buffer.

In a receive section of the transceiver, rate adaptation is performed in a manner similar to that of the transmit section, except that there are stricter timing constraints. Because some of the receive processing tasks cannot be completed until the whole frame is available, the receive section requires a minimum of three rate adaptation buffers. Similarly to the transmit section, four modules in the receive section are each independent from each other in the sense that they are all able to address the rate adaptation buffer. The four modules include a deinterleaver, an FEC decoder, a CRC-descrambler, and a constellation decoder. A timing and control section prevents contention between the four modules.

This allows the synchronization of the 4.0 kHz rate of a superframe having 68 frames to the 4.05 kHz rate of a superframe having 69 frames (68 payload frames plus a synchronization frame) without using a large amount of memory. Thus, the size and cost required to implement the ADSL transceiver is reduced.

FIG. 1 illustrates a communication system 1, according to one embodiment of the present invention, having an ADSL remote terminal 32 and an ADSL central office 40. ADSL central office 40 contains ADSL transceiver 42 and splitter 44. ADSL central office 40 is coupled to ADSL remote terminal 32 by way of twisted pair 18. ADSL remote terminal 32 includes splitter 36 and ADSL transceiver 34.

ADSL transceiver 42 is bi-directionally coupled to splitter 44, and is additionally bi-directionally coupled externally to digital network 58. ADSL transceiver 34 is bi-directionally coupled to splitter 36, and is additionally coupled to external devices 48. Splitter 44 is bi-directionally coupled to telephone 54, while splitter 36 is bi-directionally coupled to telephone 52. Splitter 44 is additionally coupled to modem 46 and splitter 36 is coupled to modem 38. Modem 38 is further coupled to external terminals 50 and modem 46 is coupled to external terminals 56.

Communication system 1 is an example of a digital communication network, where the digital network allows communication between a variety of users having computers, telephones, fax machines, modems, television sets, and any number of other communication devices. Digital network 58 is used to transmit such a variety of information, each of which has a different transmission format and frequency.

FIG. 2 illustrates ADSL transceiver 34 of FIG. 1, along with an external interleave/de-interleave memory 66. Here, ADSL transceiver 34 may be a single chip embodiment and is substantially the same as ADSL transceiver 42. Referring to FIG. 2, ADSL transceiver 34 includes digital interface unit 3, which is coupled to digital signal processing (DSP) engine and peripherals 5. Further, DSP engine and peripherals 5 is coupled to analog front end 16. Digital interface unit 3 is bi-directionally coupled to receive signals labeled "MULTIPLE BIT STREAMS", and is bi-directionally coupled to an external interleave/deinterleave memory 66.

Analog front end 16 contains analog/digital converter (A/D) 19 which is coupled to receive filter 20. Analog front

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end 16 further includes transmit amplifier 21 which is coupled to digital/analog converter (D/A) 17. Transmit amplifier 21 is further coupled to TXA port 22. Receive filter 20 is coupled to port 24. RXA port 22 is then coupled to external line interface 23. External line interface 23 is coupled to both ports 22 and 24.

DSP engine and peripherals 5 includes a digital signal processor and firmware necessary to perform various signal processing functions. These functions include a DMT modulator 13, an echo canceller clip mitigation 14, and a DMT demodulator as illustrated in FIG. 2. DMT modulator 13 has an input coupled to digital interface unit 3, and an output coupled to D/A converter 17. DMT demodulator 15 has an input coupled to A/D converter 19, and an output coupled to digital interface unit 3. Echo cancellation clip mitigation 14 is an additional signal processing function performed by DSP engine and peripherals 5, and these functions are performed on both the transmit and receive sides by subtracting echo terms of one path from the signal in the other path.

Digital interface unit 3 includes a bidirectional port for receiving and transmitting payload data, which is labeled "MULTIPLE BIT STREAMS" in FIG. 2. When receiving data for transmission, digital interface unit 3 receives transmit payload data from the MULTIPLE BIT STREAMS and outputs sets of complex symbols to DMT modulator 13. Similarly, digital interface unit 3 receives sets of complex symbols from DMT demodulator 15 and outputs receive payload data to the MULTIPLE BIT STREAMS. As part of the ADSL task, digital interface unit 3 also interleaves transmit data and de-interleaves receive data. In order to perform these complex functions, ADSL transceiver 34 requires a large amount of memory, which is preferably implemented off-chip in external interleave/de-interleave memory 66. Also, in order to minimize the number of integrated circuit pins required to access external memory, the interleave and de-interleave buffers are also preferably implemented in the same physical memory and digital interface unit 3 preferably multiplexes between interleaving and de-interleaving operations.

The operation of digital interface unit 3 is understood with reference to FIG. 3, which illustrates digital interface unit 3 in block diagram form. Digital interface unit 3 generally includes a transmit section 62, a receive section 64, and common timing and control portion 84 which coordinates the operation between the two sections. Also illustrated in FIG. 3 is an external interleave/de-interleave memory 66, which is used by both transmit section 62 and receive section 64.

Timing control block 84 generates timing signals which are necessary for the signal processing functions. Timing control block 84 also coordinates the activities of several modules in both the transmit and receive path so that their activities do not conflict. Furthermore, timing control block 84 includes a memory arbitrator that arbitrates between the transmit and receive path for access to external interleave/deinterleave memory 66.

The operation of digital interface unit 3 is better understood first by examining transmit section 62. Transmit section 62 includes a multiplexer (MUX) 68, a transmit frame memory 70, a CRC-scrambler 72, a rate adaptation buffer 74, an FEC encode block 76, an interleaver 78, a constellation encoder 80, and a constellation output buffer 82. MUX 68 has an input for receiving the MULTIPLE BIT STREAMS and is coupled to transmit frame memory 70. Transmit frame memory 70 has an input coupled to MUX



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68, and an output. CRC-scrambler 72 has an input connected to transmit frame memory 70, and an output. Rate adaptation buffer 74 has an input connected to the output of CRC-scrambler 72, two bi-directional connections to FEC encode 76 and interleaver 78, and an output connected to constellation encoder 80. Interleaver 78 also has a second bidirectional terminal connected to external interleave/deinterleave memory 66. Constellation encoder 80 has an input terminal connected to rate adaptation buffer 74, and an output connected to constellation output buffer 82. Constellation output buffer 82 has an output which is connected to DSP engine and peripherals 5 of FIG. 2.

Receive section 64 includes generally a constellation input buffer 86, a constellation decoder 88, a de-interleaver 90, an FEC decode 92, a rate adaptation buffer 94, a CRC-descrambler 96, a receive frame memory 98, and a demultiplexer (DEMUX) 100. Constellation input buffer 86 has an input connected to DSP engine and peripherals 5 of FIG. 2, and an output. Constellation decoder 88 has an input connected to the output of constellation input buffer 86, and an output. De-interleaver 90 has a first bidirectional terminal, and a second bidirectional terminal connected to external interleave/deinterleave memory 66. FEC decode 92 has a bidirectional terminal. Rate adaptation buffer 94 has an input terminal connected to the output terminal of constellation decoder 88, a first bi-directional terminal connected to the bi-directional terminal of deinterleaver 90, a second bidirectional terminal connected to the bi-directional terminal of FEC decode 92, and an output terminal. CRC-descrambler 96 has an input terminal connected to the output terminal of rate adaptation buffer 94, and an output terminal. Receive frame memory 98 has an input terminal connected to the output terminal of CRC-descrambler 96, and an output terminal connected to an input terminal of DEMUX 100. DEMUX 100 also has an output terminal which provides seven channels of data to the MULTIPLE BIT STREAMS. External interleave/deinterleave memory 66 has a bidirectional terminal coupled to the second bidirectional terminals of interleaver 78 and deinterleaver 90.

In operation, MUX 68 receives MULTIPLE BIT STREAMS which may be organized into a maximum of seven channels. Note that some of the channels need not be present in a particular application. These seven channels of payload data are then stored in corresponding portions of transmit frame memory 70. In addition, transmit frame memory 70 appends a FAST byte and a SYNC byte, defined by the ADSL standard, at the appropriate points in the frame. CRC-scrambler 72 then reads the corresponding portions of the frame from transmit frame memory 70. CRC-scrambler 72 performs an 8-bit cyclic redundancy check first on the fast data and then on the interleaved data. The scrambler function of CRC-scrambler 72 also operates first on the fast data and next on the interleaved data. CRC-scrambler 72 makes the modified transmit frame available to other signal processing blocks by writing it into rate adaptation buffer 74. In the illustrated embodiment, rate adaptation buffer 74 comprises a single static random access memory (SRAM).

FEC encode 76 performs a forward error correction encoding first on fast data and next on the interleaved data in the frame and appends redundancy bytes to the frame and stores those in appropriate portions of rate adaptation buffer 74. Interleaver 78 operates only on the interleaved portion of the frame, and reads data out of rate adaptation buffer 74 and writes data back into rate adaptation buffer 74 after performing the interleaving operation. Because the interleaving operation requires a large amount of memory, interleaver 78 uses a portion of external interleave/deinterleave memory

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66. Interleaver 78 arbitrates for use of external interleave/deinterleave memory 66 with deinterleaver 90 so that only one external memory interface using common integrated circuit pins is required. At the conclusion of the CRC-scrambling FEC encoding and interleaving operations, constellation encoder 80 reads data from rate adaptation buffer 74. Constellation encoder 80 encodes the data into complex symbols based on a bit allocation table, and may use the well-known trellis encoding method. The bit allocation table is determined at initialization between the central office and the remote terminal based on the characteristics of the transmission link. Constellation encoder 80 then provides the complex symbols to constellation output buffer 82 for further processing by DSP engine and peripherals 5.

In receive section 64, data in the form of sets of complex symbols are received from DSP engine and peripherals 5 which writes them into constellation input buffer 86. Constellation decoder 88 reads the complex symbols from constellation input buffer 86 and converts them into frame data based on a bit allocation table. In the illustrated embodiment, constellation decoder 88 includes the well-known Viterbi algorithm as an option. Note that other algorithms may also be used. Constellation decoder 88 then writes the frame data into rate adaptation buffer 94. A deinterleaver 90 performs a deinterleave operation on the interleaved portion of the received frame. Deinterleaver 90 makes use of external interleave/deinterleave memory 66 and arbitrates for usage thereof in a manner similar to interleaver 78. FEC decode 92 first performs an FEC decode operation on the fast portion of the frame data, and then performs an FEC decode operation on the interleaved portion of the frame data. If FEC decode 92 detects an error in the frame data, it performs correction within rate adaptation buffer 94. CRC-descrambler 96 reads the completed frame data out of rate adaptation buffer 94. CRC-descrambler 96 descrambles the frame data by first operating on the fast data and next on the interleaved data as well. CRC-descrambler 96 performs a CRC check on the fast data and next on the interleaved data. CRC-descrambler 96 then writes the data into receive frame memory 98. The data in receive frame memory 98 is then output to the corresponding channel selected by DEMUX 100, which become part of the MULTIPLE BIT STREAMS.

Transmit section 62 is able to perform rate adaptation by receiving data at a 4 kilohertz rate from the MULTIPLE BIT STREAMS and providing data out of constellation output buffer 80 at a rate of 4.05 kilohertz for the frame. Transmit section 62 is able to perform this rate adaptation using only a single rate adaptation buffer 74 and without the need for multiple frame buffering as in known rate adaptation techniques. Transmit section 62 includes four autonomous modules which are able to access the data in rate adaptation buffer 74 independently of one another. These four modules include CRC-scrambler 72, FEC encode 76, interleaver 78, and constellation encoder 80. Note that timing control 84 prevents contention for accesses to rate adaptation buffer 74. In addition, each of the four independent modules perform their respective functions quickly enough to prevent overflow or underflow conditions in rate adaptation buffer 74. The speed of these operations is facilitated by the use of independent modules which may each independently access rate adaptation buffer 74. As described herein, the term "independent" means that each module is capable of independently addressing needed data in rate adaptation buffer 74. However, timing and control 84 insures that there is no contention between the modules by allowing access to rate adaptation buffer 74 in a time sharing sense. The necessity

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of storing or receiving data at a four kilohertz frame rate and providing data at a 4.05 kilohertz rates creates constraints in the timing and sequence of operations of the various modules of transmit section 62. These timing constraints will be better understood with reference to both FIGS. 4 and 5.

In receive section 64 the rate adaptation problem is similar to that of the transmit side except there are stricter timing constraints. In the case of receive section 64, data is being provided from DSP and peripherals 5 at a rate of 4.05 kilohertz per frame into constellation input buffer 86. Because some of the receive processing tasks cannot be completed until the whole frame is available, receive section 64 requires a minimum of three frame buffers. Similarly to transmit section 62, in receive section 64, the four modules are each independent in the sense that they are all able to address rate adaptation buffer 64. But again, timing and control 84 must prevent contention. In addition, timing and control 84 must transfer data between the three frame buffers when particular signal processing functions have completed. These additional constraints will be better understood with reference to FIGS. 6 and 7 below.

FIG. 4 illustrates, in block diagram form, the functions performed by transmit section 62. FIG. 4 is useful in understanding the sequence of operations provided on data in transmit section 62. This sequence of processing will become helpful in the understanding of the timing constraints which will be explored further with reference to FIG. 5 below. In FIG. 4 proceeding from left to right, data is first assembled into frame memory 70. Note that elements in FIG. 4 which are in common with FIG. 3 are assigned the same reference numbers. CRC-scrambler 72 represents the first operation performed on data with reference to rate adaptation buffer 74. CRC-scrambler 72 reads data out of frame memory 70 and writes data into rate adaptation buffer 74. An FEC encode operation represents the second operation performed on the data in rate adaptation buffer 74. To perform FEC encoding, FEC encoder 76 first reads data out of rate adaptation buffer 74 and later writes data back into rate adaptation buffer 74. The interleave operation is performed by interleaver 78 and represents the third operation. In this third operation, interleaver 78 also reads data out of rate adaptation buffer 74 and subsequently writes data back into rate adaptation buffer 74. The fourth operation associated with transmit section 62 is that performed by constellation encoder 80. In performing this function, constellation encoder 80 reads data out of rate adaptation buffer 74 and converts the data into sets of complex signals. The complex symbols are not rewritten into rate adaptation buffer 74, but rather are written to constellation output buffer 82.

This sequence is used for understanding the timing constraints which are developed in FIG. 5, which illustrates a timing diagram of the transmission of a superframe of data. In FIG. 5 the upper most timing axis represents a superframe of data to be transmitted which is received at a 4 kilohertz rate. Within the superframe there are 68 frames labeled frame 0, frame 1, etc. through frames 67. Following frame 67 is a frame 0 of a succeeding frame. The time point between frame 67 and frame 0 of the next frame represents a superframe boundary. The second horizontal axis represents the reading of frames by DSP engine and peripherals 5 at the higher rate of 4.05 kilohertz. Note that there are 69 frames number 0 through 68 in the 4.05 kHz superframe. By examining the time that the four signal processing functions of FIG. 4 require, it is possible to determine a time interval labeled "PHASE" which allows transmit section 62 to synchronize the 4 kHz rate to the 4.05 kHz rate. Setting this phase value consistent with various timing constraints

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allows 68 frames to be received for transmission in the same amount of time that 69 frames are transmitted on a telephone line without requiring more than one frame buffer of memory in rate adaptation buffer 74.

As illustrated in FIG. 5, the PHASE value represents the difference in time between the start of a superframe received at the 4 kilohertz rate and the start of transmission of the same superframe at the 4.05 kilohertz rate. Note that FIG. 5 illustrates three other variables which relate to timing constraints as will be further described below. The first variable is an interval labeled "CONST" which represents the amount of time it takes constellation encoder 82 to compute the set of complex symbols for one frame of data. A second value labeled "OP1" represents the amount of time required for operations one, two and three as illustrated in FIG. 4. Finally, the interval labeled "DSP" represents the amount of time it takes DSP and peripherals 5 to read the contents of constellation output buffer 82.

FIG. 6 illustrates, in block diagram form, the signal processing functions performed on data which is stored in rate adaptation buffer 94. As before, functions which are like those performed in FIG. 3 are assigned the same reference numbers. Note that as illustrated in FIG. 6, rate adaptation buffer 94 includes a first buffer 106 labeled "RAB1", a second buffer 108 labeled "RAB2" and a third 4 kHz buffer 110. Note that in FIG. 6 the sequence of operations proceeds right to left. First, DSP and peripherals 5 provide data to constellation buffer 86 at a frame rate of 4.05 kilohertz. A constellation decoder 88 then reads data from constellation buffer 86 to perform a first function and writes the data into one of RAB1 or RAB2 which are used in an alternating fashion. When constellation decoder 88 completes processing of a frame of data that frame of data is then transferred into 4 kHz buffer 110 at an appropriate time. In the illustrated embodiment, the 4 kHz buffer is an SRAM array. At this point, constellation decoder 88 starts the use of another one of RAB1 and RAB2 for the next frame. RAB1 and RAB2 are portions of a single SRAM array. This second operation by receive section 64 is the deinterleave operation 2 performed by deinterleaver 90. The deinterleave operation is performed by reading data from 4 kilohertz buffer 110 and writing data back into 4 kHz buffer 110. The third operation is the FEC decoding provided by FEC decode 92. Likewise, FEC decode 92 reads data from 4 kHz buffer 110 and writes data back into 4 kHz buffer 110. Finally, the fourth operation performed by receiver section 60 is a CRC-descrambling operation performed by CRC-descrambler 96. To perform this operation, CRC-descrambler 96 reads data out of 4 kHz buffer 110 and writes the descrambled data into frame memory 98. Note that since constellation decoder 88 must operate for an entire frame period, the receive operation is necessarily more difficult in terms of buffering than the transmit operation. In addition, the data provider is working at a faster rate and therefore will of necessity provide more data than can be handled at the slower rate. Thus, constellation decoding is performed independently on data in a different buffer from the other three operations and an additional frame buffer is required to allow storing the overflowing data arriving at the faster 4.05 kHz rate.

FIG. 7 illustrates a timing diagram of the various events associated with receive section 64 which are helpful in understanding the timing constraints imposed by the various events. The first horizontal axis represents the sequence of frames received and provided to the multiple bit streams at the 4 kilohertz rate. As in FIG. 5 there are 68 frames of a superframe and individual frames in the superframe are illustrated including a superframe boundary between frame



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67 and frame 0 of a subsequent superframe. The second horizontal axis represents frames received from DSP and peripherals 5 through constellation buffer 86 at the 4.05 kilohertz rate. Also, in FIG. 7 are several time durations which represent constraints imposed on the sequence of events. The first variable labeled "PHASE" is the delay between the start of the 4.05 kilohertz super frame and the start of the 4 kilohertz super frame. The second variable is labeled "CONST" and represents the period of time required for constellation decoder 88 to convert the set of symbols into constellation buffer 86 into a frame of data. A third variable labeled OP2 represents the amount of time required for the deinterleaving, FEC decoding, and CRC-descrambling operations. A fourth variable labeled MOVE represents the amount of time it takes to move a frame of data from a full one of RAB1 or RAB2 into 4 kHz buffer 110. A fifth variable labeled "DSP" represents the amount of time required by DSP and peripherals 5 to write a set of symbols into constellation buffer 86 which corresponds to a complete frame of data. In addition, FIG. 7 illustrates two time points which also form constraints.

A point in time labeled "T1" is the point in time at which the received data corresponding to frame 67 is being written into either RAB1 or RAB2. A point in time labeled "T2" is the time when a MOVE operation is completed from either RAB1 or RAB2 into the 4 kHz buffer in order to accommodate the write of received data corresponding to frame 67 into RAB1 or RAB2.

While the invention has been described in the context of a preferred embodiment, it will be apparent to those skilled in the art that the present invention may be modified in numerous ways and may assume many embodiments other than that specifically set out and described above. Accordingly, it is intended by the appended claims to cover all modifications of the invention which fall within the true spirit and scope of the invention.

What is claimed is:

1. An asymmetric digital subscriber line (ADSL) transmitter, comprising:

- a transmit frame memory for receiving a bit stream at a first rate, and storing the bit stream as a frame of data;
- a cyclic redundancy check (CRC) scrambler, coupled to the transmit frame memory, for operating on the frame of data;
- a forward error correction encoder, for performing an encoding operation on the frame of data;
- an interleaver, for selectively interleaving at least a portion of the frame of data;
- a rate adaptation buffer, coupled to the CRC-scrambler, the forward error correction encoder, and the interleaver, the rate adaptation buffer for temporarily storing the frame of data after the forward error correction encoder, the interleaver, and the CRC-scrambler operate on the frame of data to provide a modified frame of data; and
- an encoder, coupled to the rate adaptation buffer, for providing a new frame of data at a second rate different from the first rate.

2. The ADSL transmitter of claim 1, wherein the rate adaptation buffer consists of only a single random access memory.

3. The ADSL transmitter of claim 1, wherein the encoder is characterized as being a constellation encoder.

4. The ADSL transmitter of claim 1, wherein the rate adaptation buffer is for temporarily storing the frame of data for an amount of time required for the encoder to transmit a previous frame of data.

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5. A method for transmitting a frame of data in a communication system, the method comprising the steps of:

- receiving the frame of data, at a first rate, in a frame memory;

- performing at least two operations on the frame of data to produce a modified frame of data, and moving the modified frame of data to a rate adaptation buffer after each of the at least two operations; and

- providing the modified frame of data to an output buffer, the output buffer providing a buffered frame of data at a second rate different from the first rate.

6. The method of claim 5, wherein the step of performing the at least two operations further comprises the steps of:

- performing a cyclic redundancy check (CRC) scrambling operation on the frame of data to produce a scrambled frame of data;

- providing the scrambled frame of data to the rate adaptation buffer;

- performing an encoding operation on the scrambled frame of data to produce an encoded scrambled frame of data;

- providing the encoded scrambled frame of data to the rate adaptation buffer; and

- performing an interleaving operation on at least a portion of the encoded scrambled frame of data to produce an interleaved encoded scrambled frame of data.

7. The method of claim 6, further comprising the steps of:

- providing the interleaved encoded scrambled frame of data to the rate adaptation buffer; and

- performing a constellation encoding operation of the interleaved encoded scrambled frame of data to produce the buffered frame of data.

8. The method of claim 7, wherein the rate adaptation buffer is cleared by the constellation encoding operation before the scrambled frame of data can be received.

9. The method of claim 7, wherein the output buffer is cleared before the constellation encoding operation is performed.

10. An asymmetric digital subscriber line (ADSL) receiver, comprising:

- a constellation decoder for receiving a frame of data at a first rate and providing a decoded frame of data;

- a rate adaptation buffer, coupled to the constellation decoder, for temporarily storing the decoded frame of data;

- a forward error correction decoder, coupled to the rate adaptation buffer, for decoding the frame of data;

- a deinterleaver, coupled to the rate adaptation buffer, for deinterleaving an interleaved portion of the frame of data;

- a cyclic redundancy check (CRC) descrambler, coupled to the rate adaptation buffer, for descrambling the frame of data to produce a descrambled frame of data; and

- a receive frame memory, coupled to the descrambler, for receiving the descrambled frame of data at a second rate, the second rate being different than the first rate.

11. The ADSL receiver of claim 10, wherein the rate adaptation buffer comprises first, second, and third portions, wherein the first and second portions alternately receive decoded frames of data from the constellation decoder, the third portion coupled to both the first and second portions and alternately receives the decoded frames of data from the first and second portions on a first in, first out basis, the third portion coupled to the CRC-descrambler, the deinterleaver, and the forward error correction decoder.

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12. The ADSL receiver of claim 10, further comprises an input buffer for receiving a plurality of frames of data and coupled to the constellation decoder.

13. The ADSL receiver of claim 10, wherein the rate adaptation buffer is for temporarily storing at least one frame of data that has arrived at the rate adaptation buffer before the at least one frame of data can be operated on by the CRC-descrambler, the deinterleaver, and the forward error correction decoder.

14. A method for receiving a frame of data in a communication system, the method comprising the steps of:

receiving the frame of data, at a first rate, in an input buffer;

decoding the frame of data and providing a decoded frame of data to a rate adaptation buffer;

performing at least two operations on the frame of data to produce a modified frame of data, and moving the modified frame of data to the rate adaptation buffer after each of the at least two operations; and

providing the modified frame of data to a receive frame memory, the receive frame memory providing the modified frame of data at a second rate different from the first rate.

15. The method of claim 14, further comprising a step of descrambling the modified frame of data before the step of providing the modified frame of data to the receive frame memory.

16. The method of claim 14, wherein the step of performing the at least two operations further comprises the steps of:

providing a decoded frame of data to one of a first portion or a second portion of the rate adaptation buffer;

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moving the decoded frame of data to a third portion of the rate adaptation buffer from the first or the second portion;

performing a deinterleaving operation on at least a portion of the decoded frame of data to produce a deinterleaved decoded frame of data;

providing the deinterleaved decoded frame of data to third portion of the rate adaptation buffer;

performing a forward error correction decoding operation on the deinterleaved decoded frame of data to produce a decoded deinterleaved frame of data;

providing the deinterleaved decoded frame of data to the third portion of the rate adaptation buffer; and

performing a cyclic redundancy check (CRC) descrambling operation on the deinterleaved decoded frame of data to produce a descrambled frame of data.

17. The method of claim 14, wherein a difference between a beginning of a first superframe at the first rate and a beginning of a second superframe at the second rate is determined by an amount of time required to perform the step of decoding the frame of data.

18. The method of claim 14, further comprising the steps of:

providing a decoded frame of data to one of a first portion or a second portion of the rate adaptation buffer; and

moving the decoded frame of data to a third portion of the rate adaptation buffer from the first portion or the second portion before a new frame of data which follows the decoded frame of data by two frames.

\* \* \* \* \*

# **EXHIBIT 17**

(12) **United States Patent**  
**Fadavi-Ardekani et al.**

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(45) **Date of Patent:** **Mar. 16, 2004**

(54) **MULTI-SESSION ASYMMETRIC DIGITAL  
SUBSCRIBER LINE BUFFERING AND  
SCHEDULING APPARATUS AND METHOD**

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\* cited by examiner

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(\*) Notice: Subject to any disclaimer, the term of this  
patent is extended or adjusted under 35  
U.S.C. 154(b) by 0 days.

(57) **ABSTRACT**

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(52) **U.S. Cl.** ..... **370/395.5**; 370/466; 370/480;  
375/222

(58) **Field of Search** ..... 370/230, 235,  
370/235.1, 395.1, 412, 428, 429, 395.5,  
480, 503, 505, 511, 512, 513, 514, 516;  
375/222

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

5,737,337 A \* 4/1998 Voith et al. .... 714/702  
5,751,741 A \* 5/1998 Voith et al. .... 714/758  
6,134,283 A \* 10/2000 Sands et al. .... 375/354  
6,233,250 B1 \* 5/2001 Liu et al. .... 370/469  
6,480,475 B1 \* 11/2002 Modlin et al. .... 370/294

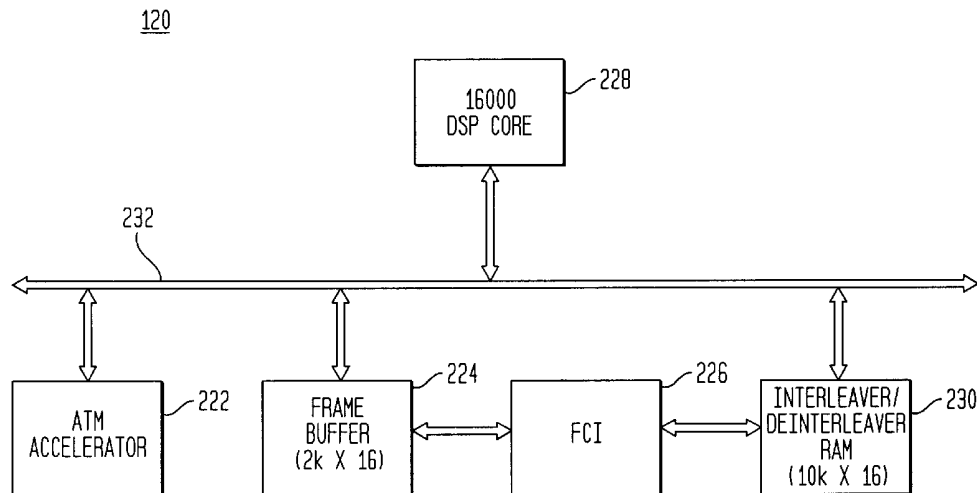
**OTHER PUBLICATIONS**

U.S. Pub No.: 2002/0167949 A1 (Bremer et al., Provisional  
Filing Date Apr. 4, 1999).\*

U.S. Pub. No.: 2002/0146014 A1 (Karlsson et al., Filing  
Date Apr. 6, 2001).\*

A transceiver for an asymmetric communication system is provided that implements a buffering and scheduling scheme that utilizes a virtual clock signal to synchronize processing of asynchronous frame data for multiple ADSL sessions. In every virtual clock cycle, the transceiver first sequentially performs transmit-processes for each active ADSL line and then sequentially performs receive-processes for each active ADSL line. An Asynchronous Transfer Mode (ATM) Accelerator provides the network interface to multiple ATM channels and communicates frame data to a Frame Buffer (FB). The FB may be used in a ping-pang fashion for the communication of data between the ATM accelerator and a Framers/Coder/Interleaver (FCI), which performs its namesake, among other, functions. The FCI also interfaces a Digital Signal Processing (DSP) core through an Interleave/De-Interleave Memory (IDIM). The DSP core generates the virtual clock signal, which schedules operation of the ATM accelerator and the FCI. IDIM holds DMT frames of data and may also be utilized in a ping-pang fashion. Memory is shared by multiple ADSL sessions and by the transmit and receive processes within an individual session.

**26 Claims, 2 Drawing Sheets**



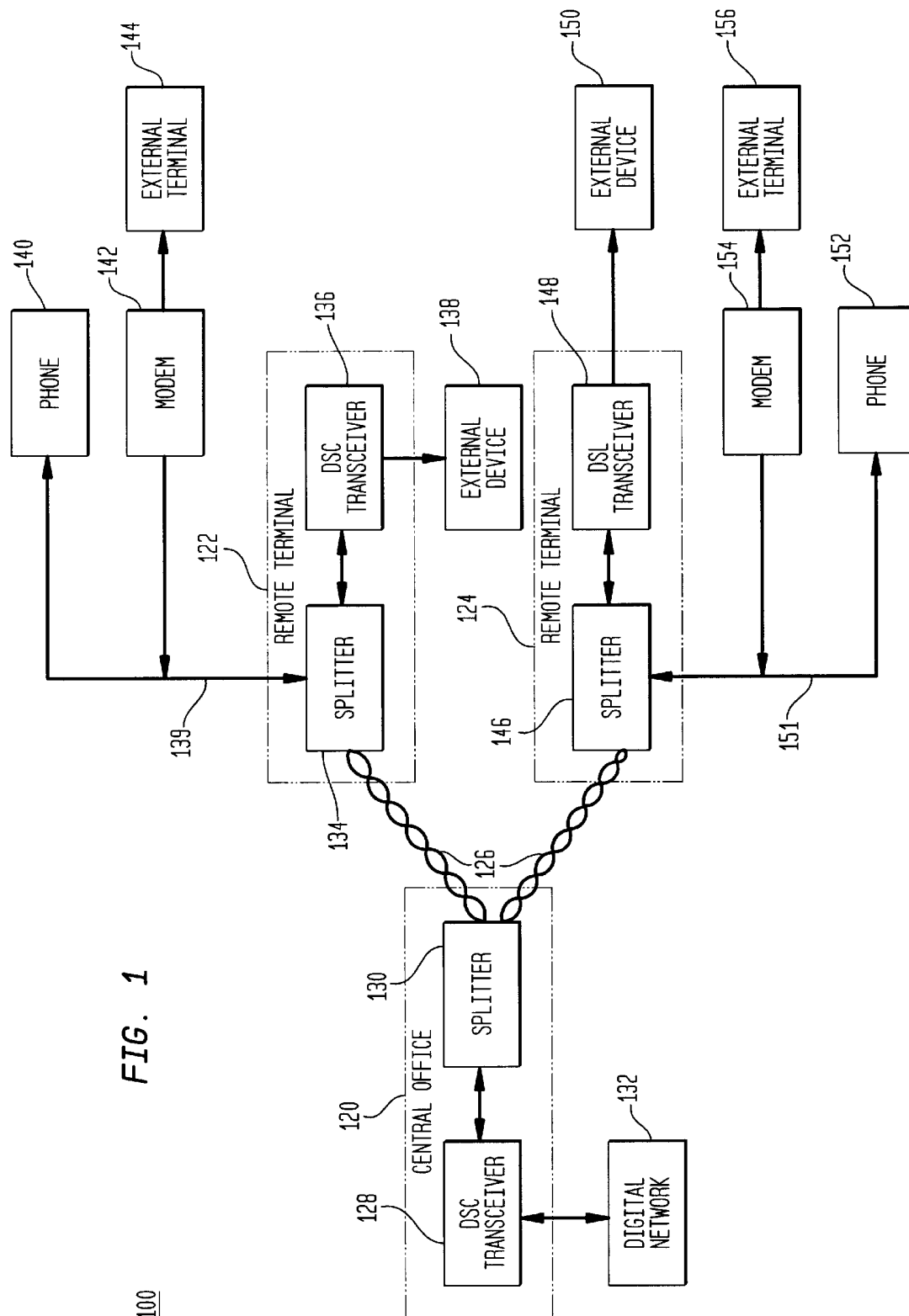


FIG. 2

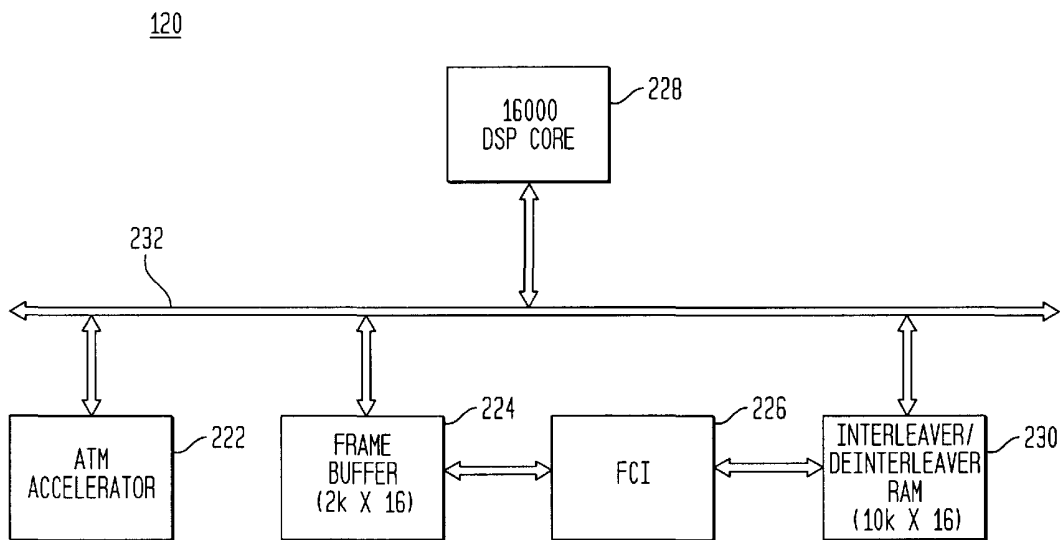
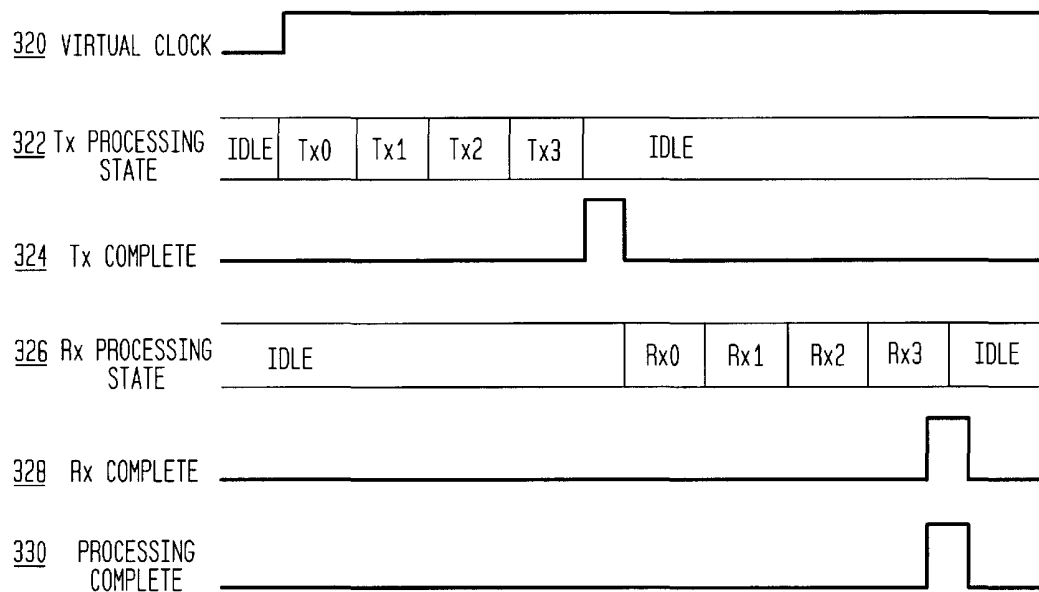


FIG. 3



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# MULTI-SESSION ASYMMETRIC DIGITAL SUBSCRIBER LINE BUFFERING AND SCHEDULING APPARATUS AND METHOD

## FIELD OF THE INVENTION

The invention relates generally to broadband communications, and more particularly to the transmission of broadband signals using twisted-pair cable.

## BACKGROUND

High-speed data communications paths are desirable for Internet access and are essential for high data rate interactive services such as video on demand. Since fiber optic cable, the preferred transmission media for such services, is not readily available in the transmission link between a network node and a user premise and is prohibitively expensive to install, it is desirable to utilize the existing Plain Old Telephone Service (POTS) infrastructure. However, current POTS wiring connections consist of copper twisted-pair media which was designed for low frequency, voice-band (0–3400 Hz) analog telephony, and does not readily support the data rates or bandwidth required for high data rate interactive services. Conventional POTS analog transmission is limited to a data rate of about 56 Kbps, which represents only a small portion of the amount of information that can be transmitted over twisted-pair media.

DSL (Digital Subscriber Line) provides a method of communicating high-bandwidth data over twisted-pair media. In addition, some forms of DSL service (e.g., ADSL) include a subdivision of the DSL bandwidth so that some bandwidth is used to provide POTS service simultaneously with data transmission. Thus, DSL enables high data rate interactive services without requiring the installation of fiber optic cable.

Asymmetrical Digital Subscriber Line (ADSL (ANSI T 1.413-1998)) is specifically designed to exploit the asymmetric nature of most multimedia communication, in which large amounts of information flow toward an end user (i.e., downstream) and only a small amount of information (e.g., interactive control information) is returned by the end user to a central office (i.e., upstream). ADSL is “asymmetric” in that most of its two-way (duplex) bandwidth is utilized to transmit downstream and only a small portion is utilized for upstream transmission. Using ADSL, approximately 6–8 Mbps of data can be sent downstream and approximately 512 Kbps can be sent upstream. Other variations of DSL (i.e., xDSL) include High bit rate DSL (HDSL) and Very high bit rate DSL (VDSL).

Many DSL technologies require that a signal splitter be installed at a remote end user location to split POTS service from the digital data transmission. However, the line split for an end user can be managed remotely from a central office using G.Lite (a/k/a DSL Lite, splitterless ADSL, and Universal ADSL), which is essentially a slower form of ADSL. Equipment installation costs are saved using G.Lite (ITU-T standard G-992.2), which provides a data rate of approximately 1.5 Mbps downstream and approximately 512 Kbps upstream.

In a conventional ADSL communication system, an ADSL transceiver at each end of a twisted-pair (a remote end user premise and a central office) connects to the twisted-pair circuit, creating information channels—a high speed downstream channel, a medium speed upstream channel, and depending on implementation, a POTS or an Integrated Services Digital Network (ISDN) channel. Each channel can

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be sub-multiplexed to form multiple, lower rate channels utilizing one of several modulation technologies. One such modulation technology, Discrete MultiTone (DMT), is a multi-carrier technique that divides the available bandwidth of twisted-pair media connections into mini-subchannels or bins. In the ADSL standard, DMT may be used to generate up to 250 separate 4.3125 KHz subchannels from 26 KHz to 1.1 Mhz for downstream transmission and up to 26 sub-channels from 26 KHz to 138 KHz for upstream transmission. Other modulation technologies used with ADSL include Carrierless Amplitude Modulation (CAP) and Multiple Virtual Line (MVL).

At the central office in a typical ADSL system, a Digital Subscriber Line Access Multiplexer (DSLAM) multiplexes/de-multiplexes a unique set of data for each of multiple ADSL lines, concentrating the ADSL lines into a single terminating device for connection onto the backbone network interconnecting central offices. An ADSL transceiver associated with each ADSL line is in communication with the DSLAM. For the unique data stream of each ADSL line, the ADSL transceiver provides data to (and receives data from) several channels with the data grouped into frames that include both payload data bytes and overhead data bytes. Data from each channel is placed in different positions in a frame depending on whether the data is interleaved or non-interleaved. In general, for transmission, a frame is assembled from the payload data of the channels with overhead bytes appended as appropriate. In particular, a cyclic redundancy check (CRC), scramble, interleave (if selected), and forward error correction (FEC) are performed on the frame data prior to its transmission. The frames in turn are grouped together into a “superframe” which includes 68 data frames plus an additional synchronization frame, which delineates the superframe boundary. A CRC is performed on all the data in a superframe and transmitted in the overhead bytes of the first frame of the next superframe. The frame data is converted into a set of complex symbols, each of which represents a number of frame bits as defined by a bit allocation table. These complex symbols are subsequently converted into an analog signal that is transmitted on a twisted-pair. Conversely, when receiving an analog signal from a twisted-pair, an ADSL transceiver must convert the analog signal into complex digital symbols, convert the complex symbols into a receive frame, and de-interleave, FEC, CRC, and de-scramble the received frame to recover payload data.

In order to provide service to multiple remote end user premises, the central office of an ADSL communication system needs to support multiple ADSL lines, each line having a session or active period of data transfer. In addition, the central office must manage asynchronous downstream and upstream data streams for each ADSL session since, the recurrence of frames containing data for/from an individual remote end user is not necessarily periodic. In a conventional ADSL communication system, the central office has an ADSL transceiver for each remote end user served by the system. Such a system is excessively duplicative in terms of transceivers and memory in each transceiver, and thus more costly than necessary to provide the desired functionality.

## SUMMARY OF THE INVENTION

The invention provides an Asymmetric Digital Subscriber Line (ADSL) transceiver that manages multiple asynchronous ADSL sessions, synchronizing the digital signal processing tasks for the sessions with a buffering and scheduling scheme such that the various transceiver components operate seamlessly (i.e., in a semi-synchronous fashion).



Utilizing this buffering and scheduling methodology, reductions in the design sizes of various transceiver components and the data flow complexity of the transceiver may be achieved.

A central office transceiver (i.e., headend processor) according to the invention includes various functional elements and memories coupled together with digital signal processing tasks synchronized by a virtual clock signal. An Asynchronous Transfer Mode (ATM) Accelerator provides the network interface to multiple ATM channels for multiple asynchronous ADSL sessions. The ATM accelerator transfers frame data to a Frame Buffer (FB) as controlled by a Digital Signal Processing (DSP) core. The FB provides a dual access memory that is used in a ping-pong fashion, based on the logic level of the virtual clock, for the communication of data between the ATM accelerator and a Framer/Coder/Interleaver (FCI). The FCI performs various processing tasks on the frame data and also interfaces the DSP core through an Interleave/De-interleave Memory (IDIM), which holds DMT frames of data and may also be utilized in a ping-pong fashion. The DSP core generates the virtual clock signal, which is approximately 4 KHz and coincides with the ADSL Discrete MultiTone (DMT) symbol rate. The DSP core controls operation of the ATM accelerator and the FCI and performs various processing tasks such as moving data to/from the FB and the IDIM.

According to the buffering and scheduling scheme of the invention, after every transition of the virtual clock signal (i.e., in every virtual clock cycle), the transceiver first steps through ADSL lines, performing FCI transmit-processes for each active ADSL line and generating a control signal after completing all transmit-processes. The FCI then again steps through ADSL lines, processing receive-processes for all active ADSL lines and generating control signals indicating completion of receive processes and completion of all processing.

In every virtual clock cycle, the DSP core provides the FCI with data by reading Receive (RX) data frames to and loading Transmit (TX) data frames from the FB after processing. The FB is divided into segments for each individual ADSL session with the same memory space used for both RX data and TX data. The FCI and ATM accelerator first perform reading processes and then loading processes, reading RX data first before loading the TX data into the FB. In this way, the same buffer can be used for both RX data and TX data, thereby permitting the FB memory to be half the size of that in a conventional ADSL transceiver arrangement. The DSP core also loads RX data frames and reads TX data frames to/from the IDIM, which may be used in a ping-pong fashion by the FCI and DSP core.

Numerous other advantages and features of the present invention will become readily apparent from the following detailed description of the invention and the embodiments thereof, from the claims and from the accompanying drawings in which details of the invention are fully and completely disclosed as a part of this specification.

#### BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, reference may be had to the following Detailed Description of exemplary embodiments thereof, considered in conjunction with the accompanying drawings, in which:

FIG. 1 illustrates, in block diagram form, an Asymmetric Digital Subscriber Line (ADSL) system/in accordance with the invention;

FIG. 2 illustrates, in block diagram form, an ADSL transceiver for a central office in accordance with the invention;

FIG. 3 illustrates, an exemplary processing sequencing for a case when four Transmit and Receive lines are enabled;

In the detailed description below, like reference numerals are used to describe the same, similar or corresponding elements in FIGS. 1-3.

#### DETAILED DESCRIPTION

A headend transceiver (i.e., central office side processor) is provided for processing Asymmetric Digital Subscriber Line (ADSL) data. The provided ADSL transceiver implements a buffering and scheduling scheme for synchronizing the digital signal processing tasks for multiple asynchronous ADSL lines. As a result, the various components of the ADSL transceiver are able to operate seamlessly (i.e., in a semi-synchronous fashion) and the design sizes of various transceiver components and the data flow complexity of the transceiver are reduced. It should be noted, however, that the ADSL transceiver of the invention may alternatively incorporate other variations of DSL (i.e., xDSL), such as High bit-rate DSL (HDSL) and Very high bit-rate DSL (VDSL).

#### Asymmetric Digital Subscriber Line Communication System

FIG. 1 illustrates, in block diagram form, an Asymmetric Digital Subscriber Line (ADSL) system in accordance with the invention. The ADSL system 100 includes a central office 120 and remote end user terminals 122-124, which are connected together copper twisted-pair media forming a telephone line 126. The central office 120 includes an ADSL transceiver according to the invention 128 and a splitter 130. Central office ADSL transceiver 128 is bi-directionally coupled to the splitter 130 and is additionally bi-directionally coupled externally to a digital network 132.

A first remote end user terminal 122 includes splitter 134 and conventional ADSL transceiver 136. ADSL transceiver 136 is bi-directionally coupled to splitter 134 and is additionally coupled to external device 138. The splitter 134 is bi-directionally coupled via a Plain Old Telephone Service (POTS) channel 139 to a telephone 140 and is additionally coupled to a modem 142. The modem 142 is further coupled to an external terminal 144. The second remote end user terminal 124 is similarly arranged. The second remote end user terminal 124 includes a splitter 146 and a conventional ADSL transceiver 148. The ADSL transceiver 148 is bi-directionally coupled to the splitter 146 and is additionally coupled to an external device 150. The splitter 146 is bi-directionally coupled via a POTS channel 151 to a telephone 152 and additionally coupled to a modem 154, which is further coupled to an external terminal 156.

The exemplary digital communication system 100 allows high-speed data communication between a variety of remote end users having computers, telephones, fax machines, modems, television sets, and any number of other communication devices. Digital network 132 is used to transmit information for a variety of high data rate interactive services, each of which may have a different transmission format and frequency. An exemplary digital communication system employing G.lite is similar to FIG. 1, with splitters 130, 134 and 146 merely replaced by a hardware device providing a direct connection to ADSL transceivers 128, 136, and 148 respectively.

#### Central Office ADSL Transceiver

FIG. 2 illustrates a central office ADSL transceiver 120 according to the invention. The transceiver implements a



buffering and scheduling scheme for synchronizing the processing of data on multiple ADSL lines (i.e., sessions), thereby enabling the various components of the transceiver to operate seamlessly (i.e., in a semi-synchronous fashion). In conventional ADSL, data arrives at and is transmitted by the ADSL transceiver asynchronously. The data is asynchronous in the sense that the recurrence of frames containing information to/from an individual end-user are not necessarily periodic. In addition, frame data does not necessarily arrive at the transceiver synchronous with a transition in a transceiver clock; the transceiver clock may not coincide with the start of any frame of data. Therefore, frame data must be buffered in order to make frame data for each ADSL line available for processing on a transition of a transceiver clock. The transceiver of the invention buffers and schedules these asynchronous communications for multi-session ADSL, synchronizing digital signal processing tasks utilizing an approximately 4 Khz virtual clock of the same frequency as the ADSL Discrete MultiTone (DMT) symbol rate. This buffering and scheduling scheme permits reductions in the design size of transceiver components and the data flow complexity of the transceiver.

The ADSL transceiver of the invention **120** is a single integrated circuit which has various component including: an Asynchronous Transfer Mode (ATM) accelerator **222**, a Frame Buffer (FB) **224**, a Framing/Code/Interleaver (FCI) **226**, a Digital Signal Processing (DSP) core **228**, and an Interleave/De-Interleave Memory (IDIM) **230**. The FCI **226** interfaces the ATM accelerator **222** through the FB **224** and interfaces the DSP core **228** through the IDIM **230**. Transceiver components that interface each other may be bi-directionally coupled via a bus **232**, which refers to a plurality of signals or conductors which may be used to transfer one or more various types of information, such as data, address, control, or status information. In a preferred embodiment, the bus **232** is a sixteen bit bus. A virtual clock signal of approximately 4 Khz, which coincides with the ADSL DMT symbol rate, is generated by the DSP core **228** and controls the operation of the ATM accelerator **222** and FCI **226**.

The Asynchronous Transfer Mode (ATM) accelerator **222** is the network interface to multiple ATM channels (not shown). The ATM accelerator provides those functions that are responsible for data transport for a plurality of data streams communicated via twisted pair media. The data may be transported on any one of a plurality of programmable bearer channels. The data is synchronized into an appropriate one of the plurality of programmable bearer channels and the channels multiplexed in the ATM accelerator as determined by the ADSL standard. The ATM accelerator subjects this framed data to various operations that calculate a plurality of complex numbers representing DMT tones. The ATM accelerator subsequently transfers this DMT tone data on the twisted-pair media. In exemplary embodiments, the ATM accelerator may include UTOPIA-2 and serial port external network interface elements.

The Frame Buffer (FB) **224** provides a dual access memory that is used in a ping-pong fashion to transfer unframed bearer channel data between the ATM accelerator **222** and the FCI **226**. "Ping-pong" means that areas of the memory buffer are alternately utilized exclusively by one agent (a transceiver component for performing some function) and then by a second agent. As one area of memory is being used by a first agent, another area of memory can be used by a different agent. As long as different agents (in this case, the ATM accelerator and the FCI) access different areas of a dual access memory, there are no memory address

conflicts that could cause communication errors. At any time, an agent is allowed to access either a ping area of memory or a pong area of memory based on the logic level of the virtual clock signal. Thus, the FB should be allocated a memory of a size sufficient to provide ping-pong functionality. In the preferred embodiment as illustrated in FIG. 2, the frame buffer is allocated as two 1 Kx16 memory blocks, since the smallest Random Access Memory (RAM) block currently available is 1 Kx16.

The Framing/Code/Interleaver (FCI) **226** interfaces the ATM accelerator **222** through the FB **224**. The FCI Supports multiple ADSL sessions and performs various tasks on payload data including: framing/de-framing, cyclic redundancy check generation/checking (CRCing), scrambling/de-scrambling, Reed-Solomon encoding/decoding, and interleaving/de-interleaving. The FCI may also provide Network Timing Reference generation and insertion, Interleave and Fast Path support, and access to its internal state and data in support of a test methodology using the DSP core as smart test controller. All functionalities of the FCI are provided as per ADSL standards. In a preferred embodiment of the invention, approximately four G.lite (ITU G.992.2) or approximately four ADSL (ANSI T1.413-1998) sessions are supported by the FCI. It should be noted that the FCI is able to support additional sessions limited only by the size of the buffers with which it is interconnected and not limited to any specific implementation.

The Digital Signal Processing (DSP) core **228** generates a virtual clock signal that controls the operation of the ATM accelerator **222** and the FCI **226**. The virtual clock signal is an approximately 4 Khz signal that coincides with the ADSL DMT symbol rate. The DSP core **228** also responds to control signals generated by the ATM accelerator **222** and FCI **226** and performs various tasks such as moving data to/from the FB **224** and the IDIM **230**. The DSP core may access the other components of the transceiver through a standard memory read/write operation. Alternatively, the components of the transceiver of the invention need not necessarily be co-located on a single computer chip. In that case the DSP core may access other transceiver components via a programmable (Direct Memory Access) DMA channels. DMA allows data to be sent directly from an attached device to the a processor's memory

In the exemplary embodiment, the transceiver uses a Digital Signal Processor (DSP) core and is preferably implemented as a core of an DSP16K single chip DSP, which is available from Lucent Technologies, Inc., of Murray Hill, N.J. it should be noted, however, that other types of processor cores may also be utilized for the DSP core. According to the invention, processing components of the transceiver communicate with the DSP core. Other processing elements having additional functionality may be added to the transceiver as needed and implemented as peripheral modules to the DSP core. Thus, the invention is not limited to the particular components disclosed herein.

The Interleave/De-Interleave Memory (IDIM) **230** provides a memory through which the FCI **226** interfaces the DSP core **228**. The IDIM holds DMT frames of data and may be utilized in a ping-pong fashion. The IDIM is used to transfer framed, coded and possibly interleaved data frames between the FCI core and the DSP Core. In addition to interleave data storage, the IDIM may contain a dedicated area for the transfer of fast path data to the DSP Core. The IDIM may be organized as 16 bit words with byte write capability to allow beneficial performance of various interleave/de-interleave processes.

In a preferred embodiment of the invention, the IDIM is allocated as 10 Kx16 (i.e., 20 K) Random Access Memory

(RAM), which supports approximately four G.lite or approximately four standard ADSL session/s at less than full interleave depth. The size of the IDIM and the interleave depth may be varied so that a different number of sessions may be supported by the transceiver of the invention. The size of the IDIM is derived as follows. A simple implementation of a transmit interleaver for G.lite communication requires 4 Kbytes per session for downstream processing, derived by multiplying the maximum codeword length by the maximum interleaver depth. The simple G.lite transmit interleaver also requires 2 Kbytes per session for upstream processing. Therefore, 24 Kbytes of RAM is required to support four G.lite sessions. Similarly, a simple implementation of a transmit interleaver for standard ADSL requires 16 Kbytes per session for downstream processing and 2 Kbytes per session for upstream processing, for a total of 72 Kbytes for four sessions. A fast path buffer is also required for fast path data in both the interleave and de-interleave processes and requires 256 bytes of RAM per session, or a total of 1 K bytes for four sessions. Since the smallest RAM block currently available is 1 Kx16, 1 Kx16 or 2 Kbytes must be allocated for the fast path buffer per direction. Therefore, a simple implementation of an interleaver would require 76 Kbytes for four standard ADSL sessions (64 K interleave +8 K de-interleave +4 K fast path). An optimal implementation of the interleaver according to the method of the invention utilizes the same memory for receive data and transmit data and thus requires 20 Kbytes to support a standard ADSL session at full interleave depth (16 K interleave & de-interleave +4 K fast path). With a lesser interleave depth, additional sessions may be supported with the same size buffer. With a larger buffer, additional session may be supported.

It should be noted that in a preferred embodiment, the firmware required for performing processing tasks associated with the central office is resident on the single integrated circuit transceiver of the invention. As functions implemented in hardware are typically executed more quickly than those implemented in software, for optimal speed, central office transceiver of the invention implements its functions in hardware so that data is transmitted at a high rate. It should be noted, however, that similar functionality can be provided in a software implementation.

#### Buffering and Scheduling Scheme

To provide ADSL service, normal operation of the ADSL transceiver of the invention requires that, in every virtual clock cycle, the DSP core provide the FCI with data by reading one or more frames of Receive (RX) data from the FB (Frame Buffer) and loading one or more frames of Transmit (TX) data to the FB. In addition, the DSP core needs to load one or more frames of RX data to the IDIM and read one or more frames of TX data from the IDIM.

FIG. 3 depicts an exemplary processing sequence according to the invention for a case when four ADSL lines are enabled (i.e., four sessions are active). FCI processing is initiated by a transition of the virtual clock signal 320. Logic within the FCI captures the state of the virtual clock signal on successive CLK rising edges to detect the transition. Virtual clock signal transitions are generated by the DSP Core at an approximately 4 KHz rate (i.e., approximately 69/68\*4 KHz), locked to the modem frame rate and local timing reference. According to the buffering and scheduling scheme of the invention, after every transition of the virtual clock signal (i.e., in every virtual clock cycle), the FCI core first processes TX data for each active ADSL line 322 (reading from the FB, framing, CRCing, scrambling, encoding

and interleaving). After processing TX data, the FCI core then processes RX data for each active ADSL line 326 (deinterleaving, decoding, CRCing, descrambling, and deframing, writing to the FB). This sequence of operations minimizes memory requirements by allowing the RX data to overwrite the same memory area in the FB that is used by the TX data, thereby permitting the size of the FB to be half that of a conventional ADSL transceiver. Since buffers/memory space consume integrated circuit area and add to the cost of a device, the memory savings and corresponding reduction in buffer size permitted by the invention reduces integrated circuit area and ADSL transceiver cost. In addition, since the single transceiver sequentially performs processing for multiple ADSL sessions, a central office that utilizes the ADSL transceiver of the invention consistently requires a lesser number of ADSL transceivers than prior art ADSL communications systems. While described in terms of an ADSL transceiver, the buffering and scheduling scheme of the invention may also be utilized in transceivers for various xDSL communication systems including High bit-rate DSL (HDSL) and Very high bit rate DSL (VDSL).

In a given virtual clock processing cycle, the stream processing state machine (i.e., FCI) will first begin processing TX data. The FCI will step through each TX line in increasing order, testing for enabled lines and initiating a TX processing state for a line as required 322. If a TX line is not enabled, the FCI immediately evaluates the next TX line. After evaluating all TX lines and processing all enabled TX lines, the FCI signals the DSP core that all TX processes are complete (TX\_Complete 324). Note that, because of the processing cycle operation, all TX lines are modem frame aligned when a processing cycle is complete and TX line data resides in the IDIM.

Once TX processes are complete, the FCI begins processing RX data. The FCI steps through each RX lines in increasing order, testing for enabled lines and initiating a RX processing state for a line as required 326. If an RX line is not enabled, the FCI immediately evaluates the next RX line. After evaluating all RX lines and processing all enabled RX lines, the FCI signals the DSP core that all RX processes are complete (RX\_Complete 328) and that all processing is complete (Processing\_Complete 330). Note that, because of the processing cycle, all RX Lines must be modem frame aligned when placed in the IDIM for processing by the FCI. The DSP core may require additional memory to perform this alignment, which may have some impact on overall RX path latency. In every DMT symbol cycle (i.e., virtual clock cycle), the FCI will load the FB, which is divided into segments for each individual ADSL session, with received data after receiver processing. The same memory space in the FB is used for both RX data and TX data. The FCI and the ATM accelerator always start the reading process and then the loading process. That is, the ATM accelerator reads RX data first before loading the TX data into the frame buffer. In this way, the same buffer can be used for both RX data and TX data, thereby permitting the size of the FB to be half that of a conventional ADSL transceiver arrangement.

The IDIM may also be used in a ping-pong fashion by the FCI and the DSP core based on the virtual clock cycle. For example, between the events of the virtual clock signal transition and the rising edge of the TX processes are complete signal (TX\_Complete 324), the DSP core may load new DMT frames of RX data to a portion of the IDIM used as de-interleave memory while the FCI is using a portion of the IDIM as interleave memory. Between the events of TX\_Complete 324 and signal that all RX processes are complete (RX\_Complete 328), the DSP core can

read TX data from the portion of the IDIM used as interleave memory while FCI is accessing the portion of the IDIM used as de-interleave memory.

#### Conclusion

There has been described and illustrated herein, an method and apparatus for synchronizing the asynchronous data processing tasks for multiple Asymmetric Digital Subscriber Line (ADSL) sessions using a single ADSL transceiver. The headend ADSL transceiver of the invention implements a buffering and scheduling scheme such that various transceiver components operate seamlessly (i.e., in a semi-synchronous fashion) and share memory. Based on a virtual clock signal that coincides with the DMT symbol rate, the transceiver steps through all ADSL lines and processes receive tasks. After completing receive tasks, the transceiver, steps through all ADSL lines and processes transmit tasks. Thus, the same memory may be used by each of multiple ADSL sessions and by both transmit processes and receive processes. Thus, a lesser number of transceivers, each transceiver utilizing a lesser amount of memory, may be used to implement an ADSL communication system according to the invention.

It is to be understood that the invention is not limited to the illustrated and described forms and embodiments contained herein. It will be apparent to those skilled in the art that various changes using different configurations and functionally equivalent components and programming may be made without departing from the scope of the invention. Thus, the invention is not considered limited to what is shown in the drawings and described in the specification and all such alternate embodiments are intended to be included in the scope of this invention as set forth in the following claims.

What is claimed is:

1. A digital subscriber line (DSL) transceiver for a plurality of DSL sessions, said DSL transceiver comprising:

an asynchronous transfer mode (ATM) accelerator interfacing a plurality of ATM channels for each of said plurality of DSL sessions, said ATM accelerator operative to convert a first analog signal to a first bit stream, said ATM accelerator operative to convert a second bit stream, said ATM accelerator operative to convert a second bit stream to a second analog signal;

a frame memory bi-directionally coupled to said ATM accelerator, said frame memory operative to receive a bit stream and store said bit stream as a frame of data;

a framer/coder/interleaver (FCI) bi-directionally coupled to said frame memory, said FCI operative to perform a data operation on said frame of data;

an interleave/de-interleave memory (IDIM) bi-directionally coupled to said FCI, said IDIM operative to receive said frame of data and store said frame of data; and

a digital signal processing (DSP) core for performing a processing task, said DSP core bi-directionally coupled to said ATM accelerator, said frame memory and said IDIM,

wherein said DSP core includes a means to generate a periodic signal, wherein, responsive to said periodic signal, said transceiver performs a transmit process sequentially for a first subset of said plurality of DSL sessions and performs a receive process sequentially for a second subset of said plurality of DSL sessions.

2. The DSL transceiver of claim 1, wherein said periodic signal is generated at a frequency of 69/68×4 KHz.

3. The transceiver of claim 1, wherein said data operation performed by said FCI is selected from the group consisting of framing, de-framing, error checking, scrambling, de-scrambling, encoding, de-coding, interleaving and de-interleaving.

4. The transceiver of claim 1, wherein said FCI further includes

a means for framing/de-framing said frame of data;

a means for error check generation and evaluation of said frame of data;

a means for scrambling/de-scrambling said frame of data;

a means for encoding/de-coding said frame of data; and

a means for interleaving/de-interleaving said frame of data.

5. The DSL transceiver of claim 1, wherein said FCI further includes:

a means for performing a transmit process sequentially for a first subset of said plurality of DSL sessions;

a means for generating a first signal indicating said transmit process for said first subset of said plurality of DSL sessions has been performed;

a means for performing a receive process sequentially for a second subset of said plurality of DSL sessions; and

a means for generating a second signal indicating said receive process for said second subset of DSL sessions has been performed.

6. The DSL transceiver of claim 1, wherein said FCI further includes

a means for generating and inserting a network timing reference;

a means providing interleave and fast path support; and

a means providing access to internal state and data of said FCI.

7. The DSL transceiver of claim 1, wherein said DSP core includes

a means to move said bit stream between said ATM accelerator and said frame memory;

a means to move said frame of data to said IDIM.

8. The DSL transceiver of claim 1, wherein said frame memory operates in a ping-pang fashion based on said periodic signal.

9. The DSL transceiver of claim 1, wherein said frame memory is a RAM of a size that supports at least two of said frames of data and operates in a ping-pang fashion.

10. The DSL transceiver of claim 1, wherein said IDIM further includes a fast path memory.

11. The DSL transceiver of claim 1, wherein said IDIM operates in a ping-pang fashion based on said periodic signal.

12. The DSL transceiver of claim 1, wherein said IDIM is a RAM of a size that supports at least four full depth G.lite sessions or approximately one full depth standard ADSL session.

13. The DSL transceiver of claim 1, wherein each of said plurality of DSL sessions supported by said DSL transceiver is XDSL selected from the group consisting of asymmetric DSL (ADSL), High bit-rate DSL (HDSL), and Very high bit rate DSL (VDSL).

14. The DSL transceiver of claim 1, wherein each of said plurality of DSL sessions supported by said DSL transceiver is modulated according to a modulation technology selected from the group consisting of Discrete Multitone, Carrierless Amplitude Modulation, and Multiple Virtual Line.

15. A method of buffering and scheduling for a multi-session digital subscriber line (DSL) transceiver, said

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method comprising the steps of generating a periodic signal, said periodic signal having a rising edge and a declining edge;

responsive to said rising edge of said periodic signal, sequentially performing a transmit process for each of a first plurality of DSL sessions, said transmit process utilizing a first memory;

generating a first signal indicative of a completion of said transmit process for said first plurality of DSL sessions; responsive to said first signal, sequentially performing a receive process for a second plurality of DSL sessions, said receive process utilizing a second memory; and generating a second signal indicative of a completion of said receive process for said second plurality of DSL sessions.

**16.** The method of buffering and scheduling of claim **15** wherein said first memory and said second memory are the same.

**17.** The method of buffering and scheduling of claim **16** wherein said first memory and said second memory are operated in a ping-pang fashion based on a state of said periodic signal.

**18.** A digital subscriber line (DSL) transceiver for transmitting and receiving data for a plurality of DSL sessions, said DSL transceiver composing:

an asynchronous transfer mode (ATM) accelerator interfacing a plurality of asynchronous transfer mode channels for each of a plurality of DSL sessions, said ATM accelerator including a means to perform a first transmit process and a means to perform a first receive process on frame data;

a frame buffer for holding said frame data;

a framer/coder/interleaver (FCI) interfacing said ATM accelerator through said frame buffer, said FCI including a means to perform a second transmit process and a means to perform a second receive process on said frame data;

an interleave/de-interleave memory (IDIM); and

a digital signal processing (DSP) core interfacing said FCI through said IDIM, said DSP core including a means to perform a third transmit process and a means to perform a third receive process on said frame data;

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wherein said first transmit process, said second transmit process and said third transmit process are characterized as transmit processing, and said first receive process, said second receive process and said third receive process are characterized as receive processing; and

wherein said DSP core includes a means to generate a periodic signal, said periodic signal operative to initiate a performance of transmit processing sequentially for a first subset of said plurality of DSL sessions and a performance of a receive processing sequentially for a second subset of said plurality of DSL sessions.

**19.** The DSL transceiver of claim **18**, wherein said periodic signal is generated at a frequency of 69/68×4

KhZ.

**20.** The DSL transceiver of claim **18**, wherein said first transmit process converts a first bit stream to a first analog signal and said first receive process converts a second analog signal to a second bit stream.

**21.** The DSL transceiver of claim **18**, wherein said second transmit process is selected from the group consisting of framing, error check generation, scrambling, encoding, and interleaving.

**22.** The DSL transceiver of claim **18**, wherein said second receive process is selected from the group consisting of de-framing, error check evaluation, de-scrambling, de-coding and de-interleaving.

**23.** The DSL transceiver of claim **18**, wherein said third transmit process and said third receive process comprises moving said frame data.

**24.** A DSL transceiver of claim **18**, wherein said frame buffer is a RAM buffer operated in a ping-pang fashion based on said periodic signal.

**25.** A DSL transceiver of claim **18**, wherein said IDIM is a RAM buffer operated in a ping-pang fashion based on said periodic signal.

**26.** A DSL transceiver of claim **18**, wherein said IDIM is a RAM buffer sized to support at least four full depth G.lite sessions or approximately one full depth standard ADSL session.

\* \* \* \* \*

# **EXHIBIT 18**



I n t e r n a t i o n a l   T e l e c o m m u n i c a t i o n   U n i o n

**ITU-T**

TELECOMMUNICATION  
STANDARDIZATION SECTOR  
OF ITU

**G.993.1**

(06/2004)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA,  
DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Access networks

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**Very high speed digital subscriber line  
transceivers**

ITU-T Recommendation G.993.1

ITU-T



ITU-T G-SERIES RECOMMENDATIONS  
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*For further details, please refer to the list of ITU-T Recommendations.*

## **ITU-T Recommendation G.993.1**

### **Very high speed digital subscriber line transceivers**

#### **Summary**

G.993.1 VDSL (Very high speed Digital Subscriber Line) permits the transmission of asymmetric and symmetric aggregate data rates up to tens of Mbit/s on twisted pairs. G.993.1 includes worldwide frequency plans that allow asymmetric and symmetric services in the same group of twisted pairs (known as a binder). G.993.1 transceivers must overcome many types of ingress interference from radio and other transmission techniques that occur in the same frequencies of typical deployment scenarios. Similarly, G.993.1 transmission power transmission levels have been designed to minimize potential egress interference into other transmission systems. As with other Recommendations in the G.99x series, G.993.1 uses G.994.1 to handshake and initiate the transceiver training sequence.

#### **Source**

ITU-T Recommendation G.993.1 was approved on 13 June 2004 by ITU-T Study Group 15 (2001-2004) under the ITU-T Recommendation A.8 procedure.



## FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

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## ITU-T Recommendation G.993.1

### Very high speed digital subscriber line transceivers

#### 1 Scope

G.993.1 VDSL (Very high speed Digital Subscriber Line) permits the transmission of asymmetric and symmetric aggregate data rates up to tens of Mbit/s on twisted pairs. G.993.1 is an access technology that exploits the existing infrastructure of copper wires that were originally deployed for POTS services. While POTS uses approximately the lower 4 kHz and ADSL/HDSL use approximately 1 MHz of the copper wire spectrum, G.993.1 uses up to 12 MHz of the spectrum. G.993.1 can be deployed from central offices or from Fibre-fed cabinets located near the customer premises.

G.993.1 includes worldwide frequency plans that allow asymmetric and symmetric services in the same group of wire pairs (known as a binder). This is accomplished by designating frequency bands for the transmission of upstream and downstream signals.

G.993.1 transceivers must overcome many types of ingress interference from radio and other transmission techniques that occur in the same frequencies of typical deployment scenarios. Similarly, G.993.1 transmission power levels have been designed to minimize potential egress interference into other transmission systems.

As with other Recommendations in the G.99x series, G.993.1 uses G.994.1 to handshake and initiate the transceiver training sequence.

It has been agreed in the ITU-T to develop a subsequent VDSL2 Recommendation that specifies only DMT modulation, and that is based on this Recommendation (VDSL) and on ITU-T Rec. G.992.3 (ADSL2).

#### 2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

- ITU-T Recommendation G.117 (1996), *Transmission aspects of unbalance about earth*.
- ITU-T Recommendation G.227 (1988), *Conventional telephone signal*.
- ITU-T Recommendation G.994.1 (2003), *Handshake procedures for digital subscriber line (DSL) transceivers*.
- ITU-T Recommendation G.996.1 (2001), *Test procedures for digital subscriber line (DSL) transceivers*.
- ITU-T Recommendation G.997.1 (2003), *Physical layer management for digital subscriber line (DSL) transceivers*.
- ITU-T Recommendation I.432.1 (1999), *B-ISDN user-network interface – Physical layer specification: General characteristics*.
- ITU-T Recommendation O.9 (1999), *Measuring arrangements to assess the degree of unbalance about earth*.



- ISO/IEC 3309:1993, *Information technology – Telecommunications and information exchange between systems – High-level data link control (HDLC) procedures – Frame structure*.

### 3 Definitions

This Recommendation defines the following terms:

**3.1 bit error ratio:** The ratio of the number of bits in error to the number of bits sent over a period of time.

**3.2 channel:** A connection conveying signals between two blocks (the conveyed signals represent information). Channels also convey signals between a block and the environment. Channels may be unidirectional or bidirectional.

**3.3 connection:** An association of transmission channels or circuits, switching and other functional units set up to provide a means for a transfer of user, control and management information between two or more end points (blocks) in a telecommunication network.

**3.4 downstream:** Information flow whose direction is from an End-Service Provider System to an End-Service Consumer System.

**3.5 electrical length:** An estimate of the loop attenuation, assuming that all the sections of cable obey a  $\sqrt{f}$  attenuation characteristic. Specifically, the electrical length is the attenuation, in dB at 1 MHz, of an equivalent hypothetical loop with a perfect  $\sqrt{f}$  attenuation characteristic.

NOTE – The attenuation caused by bridged taps does not follow a  $\sqrt{f}$  characteristic, and thus the effects of bridged taps may not be accurately represented in the estimate.

**3.6 interface:** A point of demarcation between two blocks through which information flows from one block to the other. See logical- and physical-interface definitions for further details. An interface may be a physical interface or a logical interface.

**3.7 layer/sublayer:** A collection of objects of the same hierarchical rank.

**3.8 logical information flow path:** A sequence of information transfers from an initial information source object to a terminal information destination object, either directly or through intermediate objects. Different physical information flow paths may be associated with a logical information flow path segment or with the entire path, in different implementations.

**3.9 logical (functional) interface:** An interface where the semantic, syntactic, and symbolic attributes of information flows are defined. Logical interfaces do not define the physical properties of signals used to represent the information. A logical interface can be an internal or external interface. It is defined by a set of information flows and associated protocol stacks.

**3.10 management plane (MP):** A plane that contains management information.

**3.11 management information:** Information exchanged by Management Plane objects; it may contain information or control information.

**3.12 network:** A collection of interconnected elements that provide connection services to users.

**3.13 network control function:** The network control function is responsible for the error-free receipt and transmission of content flow information to and from the server.

**3.14 network termination (NT):** The element of the Access Network performing the connection between the infrastructures owned by the Access Network operator and the Service-Consumer System (ownership decoupling). The NT can be passive or active, transparent or not.

**3.15 noise margin:** The maximum amount by which the reference noise level can be increased during a BER test without causing the modem to fail the BER requirement.

**3.16 physical interface:** An interface where the physical characteristics of signals used to represent information and the physical characteristics of channels used to carry the signals are defined. A physical interface is an external interface. It is fully defined by its physical and electrical characteristics. Logical information flows map to signal flows that pass through physical interfaces.

**3.17 plane:** A category that identifies a collection of related objects, e.g., objects that execute similar or complementary functions, or peer objects that interact to use or to provide services in a class that reflects authority, capability, or time period. Management-plane service objects, for example, may authorize ISP-clients' access to certain control-plane service objects that in turn may allow the clients to use services provided by certain user-plane objects.

**3.18 primitives:** Basic measures of performance, usually obtained from digital signal line codes and frame formats, or as reported in overhead indicators from the far end. Performance primitives are categorized as events, anomalies, and defects. Primitives may also be basic measures of other quantities (e.g., ac or battery power), usually obtained from equipment indicators.

**3.19 reference point:** A set of interfaces between any two related blocks through which information flows from one block to the other. A reference point comprises one or more logical (non-physical) information-transfer interfaces, *and* one or more physical signal-transfer interfaces.

**3.20 SNR margin:** The modem's estimate of the maximum amount by which the receiver noise (internal and external) could be increased without causing the modem BER to fail the BER requirement.

**3.21 symbol:** A bit or a defined sequence of bits.

**3.22 system:** A collection of interacting objects that serves a useful purpose; typically, a primary subdivision of an object of any size or composition (including domains).

**3.23 upstream:** Information flow whose direction is from an End-Service Customer System to an End-Service Provider System.

**3.24 user:** A service-consuming object or system (block).

**3.25 user plane (UP):** A classification for objects whose principal function is to provide transfer of end-user information: user information may be user-to-user content (e.g., a movie), or private user-to-user data.

#### 4 Abbreviations

This Recommendation uses the following abbreviations:

ATM	Asynchronous Transfer Mode
DS	Downstream
DSL	Digital Subscriber Line
EIO	External Interface Adapter
eoc	Embedded Operations Channel (between the VTU-O and VTU-R)
FDD	Frequency Division Duplexing
FEC	Forward Error Correction
HEC	Header Error Control
ISDN	Integrated Services Digital Network
LCD	Loss of Cell Delineation
LSB	Least Significant Bit

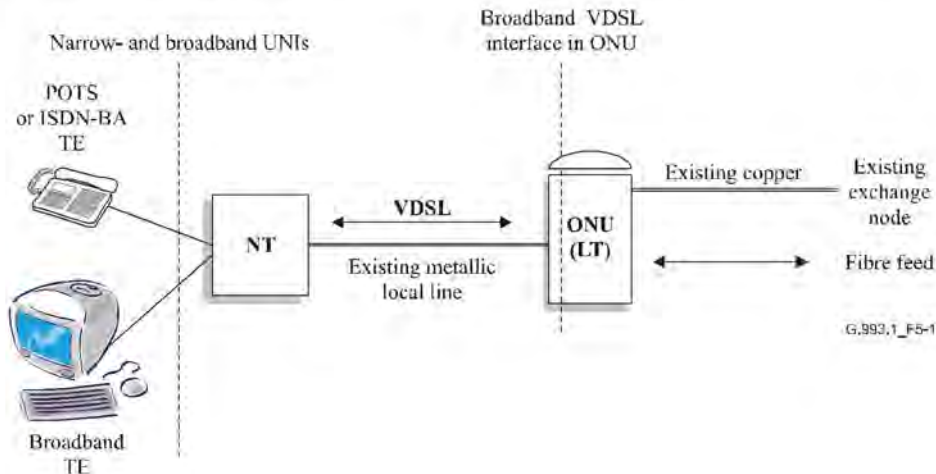


LT	Line Termination
MIB	Management Information Base
MSB	Most Significant Bit
NMA	Network Management Agent
NT	Network Termination
NTR	Network Timing Reference
OAM	Operations, Administration and Maintenance
OC	Overhead Channel
ONU	Optical Network Unit
PHY	Physical Layer
PMD	Physical Media Dependent
PMS	Physical Media Specific
PMS-TC	Physical Media Specific-Transmission Convergence
PSD	Power Spectral Density
PTM	Packet Transfer Mode
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RF	Radio Frequency
SNR	Signal-to-Noise Ratio
STP	Set of Transmission Parameters
TBD	To Be Determined
TC	Transmission Convergence
TCM	Time Compression Multiplex
TPS	Transmission Protocol Specific
TPS-TC	Transport Protocol Specific-Transmission Convergence
Tx	Transmitter
UPBO	Upstream Power Back-off
US	Upstream
VDSL	Very high speed Digital Subscriber Line
VME_O	VTU-O Management Entity
VME_R	VTU-R Management Entity
VTU	VDSL Transceiver Unit
VTU-O	VTU at the ONU
VTU-R	VTU at the Remote site
VTU-x	Any one of VTU-O or VTU-R
xDSL	Generic term covering the family of all DSL technologies, e.g., DSL, HDSL, ADSL, VDSL

## 5 Reference models

### 5.1 General reference models

Figure 5-1 shows the reference configuration used for G.993.1. It is essentially a Fibre to the Node architecture with an Optical Network Unit (ONU) sited in the existing metallic access network (or at the serving Local Exchange or Central Office). The first architectural model covers Fibre-to-the-cabinet (FTTCab) type of deployment; the second one is Fibre-to-the-exchange (FTTEx) type of deployment. Existing unscreened twisted metallic access wire-pairs are used to convey the signals to and from the customer's premises.



**Figure 5-1/G.993.1 – General reference model**

The reference configuration provides two or four data paths with bit rate under the control of the network operator, consisting of one or two downstream and one or two upstream data paths. A single path in each direction can be of high latency (with lower BER expected) or lower latency (with higher BER expected). Dual paths in each direction provide one path of each type. The dual latency configuration is thought to be the minimum that is capable of supporting a sufficient full service set, although there are organizations supporting both the single latency model with programmable latency, and others requesting more than two paths/latencies. The model assumes that Forward Error Correction (FEC) will be needed for part of the payload and that deep interleaving will be required to provide adequate protection against impulse noise.

The model introduces service-splitter functional blocks to accommodate shared use of the physical transmission media for VDSL and either POTS or ISDN-BA. The rationale behind this is that network operators are then free to evolve their networks in one of two ways: complete change out or overlay. An active Network Termination (NT) provides termination of the point-to-point VDSL transmission system and presents a standardized set of User Network Interfaces (UNIs) at the customer's premises. The NT provides the network operator with the ability to test the network up to the UNI at the customer's premises in the event of a fault condition or via nighttime routing. The home wiring transmission system is outside the scope of this Recommendation.

It is envisaged that VDSL will find applications in the transport of various protocols. For each application different functional requirements must be developed for the Transport Protocol Specific-Transmission Convergence Layer (TPS-TC). This specification covers the functional requirements for the transport of ATM and PTM. However, the G.993.1 core transceiver shall be capable of supporting future additional applications. VDSL service should non-invasively coexist with the narrow-band services on the same pair. Failure of power to the broadband NT or failure of

the VDSL service shall not affect any existing narrow-band services. This may imply that the splitter filter is of a passive nature not requiring external power in order to provide frequency separation of the VDSL and existing narrow-band signals.

POTS, if present, shall continue to be powered from the existing exchange node and a DC path is required from the local exchange to the customer telephone. Similarly, a DC path is required for ISDN-BA in order to provide remote power feeding to the ISDN-BA NT (and that emergency power can be provided by the local exchange for one ISDN terminal in the event of loss of power at the subscriber premises).

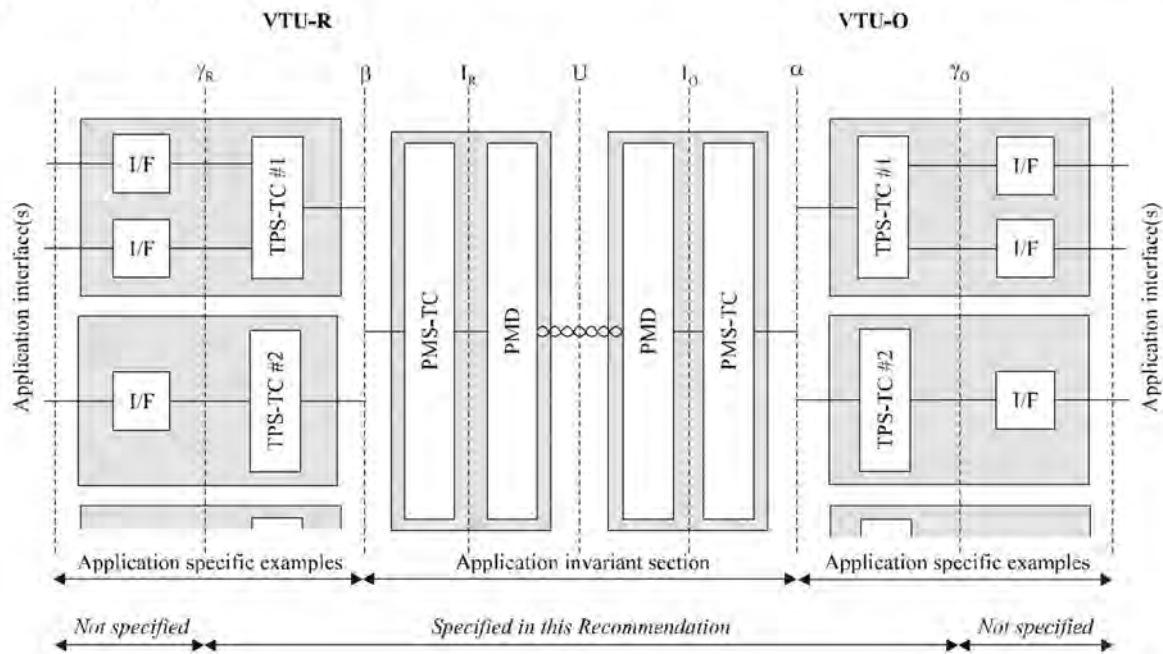
POTS and ISDN-BA cannot exist simultaneously on the same pair at present. Network Operators may provide one or the other but not both over a single wire-pair. Network Operators may choose to provide VDSL on access lines without any narrow-band services.

The broadband NT is not required to be powered remotely.

Repeated operation is not a requirement for G.993.1.

## 5.2 Functional reference model

One of the TPS-TC in Figure 5-2 may be assigned for management purposes and is called Overhead Channel TC (OC-TC).



G.993.1\_F5-2

Figure 5-2/G.993.1 – VTU-x functional reference model



### 5.3 Protocol reference model

Figure 5-3 shows the G.993.1 protocol reference model.

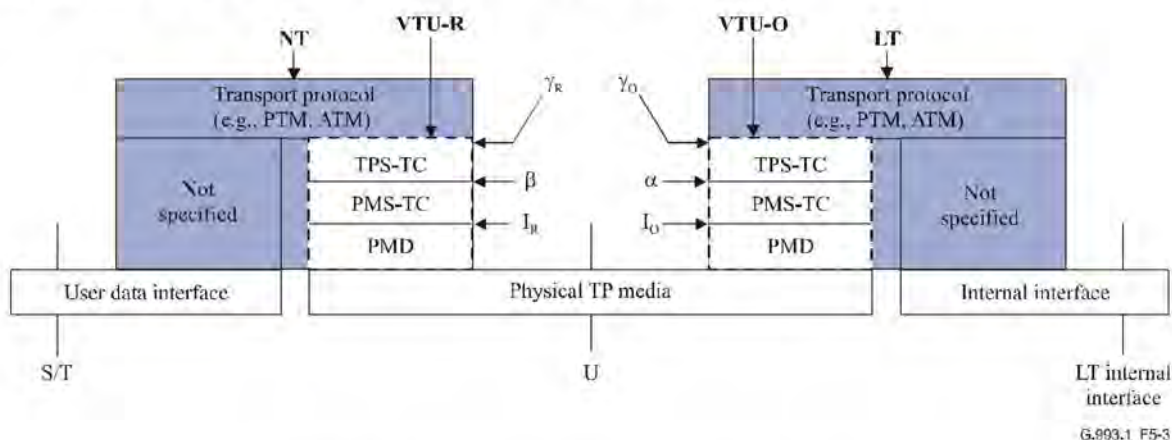


Figure 5-3/G.993.1 – VTU-x protocol reference model

## 6 Transmission medium interface characteristics

This clause specifies the interface between the transceiver and the transmission medium (U-O2 and U-R2 reference points – see Figure 8 bis/G.995.1/Amd.1 named G.993.1 System Reference Model). For the purposes of this Recommendation, the U-O2/U-R2 and U interfaces are spectrally equivalent.

### 6.1 Duplexing method

G.993.1 transceivers shall use Frequency Division Duplexing (FDD) in separating upstream and downstream transmission.

G.993.1 systems use a four-band plan that starts at 138 kHz and extends up to 12 MHz. The four frequency bands denoted as DS1, US1, DS2, and US2, for the first downstream band, the first upstream band, the second downstream band, and the second upstream band, respectively, as shown in Figure 6-1, shall be allocated according to the band separating frequencies  $f_1, f_2, f_3, f_4$  and  $f_5$ .

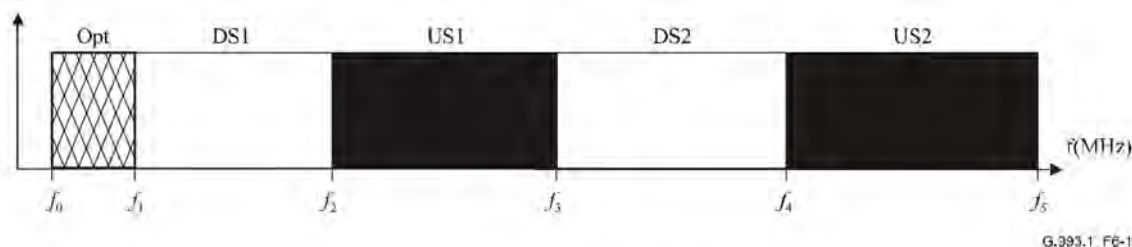


Figure 6-1/G.993.1 – G.993.1 band allocation

The use of the band between 25 kHz ( $f_0$ ) and 138 kHz ( $f_1$ ) shall be negotiated using G.994.1. The G.994.1 handshake mechanism indicates and selects (see 12.1 and 12.2) one of the following:

- If the band is to be used for upstream, bit "OptUp".
- If the band is to be used for downstream, bit "OptDn".

See Annexes A, B and C for the specifics of  $f_0, f_1, f_2, f_3, f_4$  and  $f_5$  for the Bandplans.

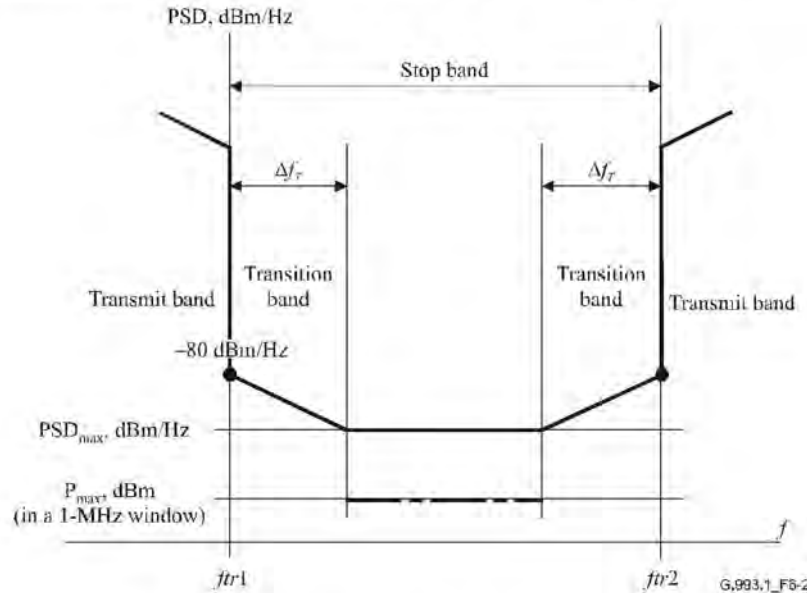
## 6.2 Power Spectral Density (PSD)

### 6.2.1 Transmit bands

See Annexes D, E and F.

### 6.2.2 Stop bands

The Power Spectral Density (PSD) mask inside the stop bands shall be as defined in Figure 6-2. The narrow-band PSD mask applies between band separating frequencies  $f_{tr1}$  and  $f_{tr2}$ . The wideband power limit applies in that part of the receive band lying between the transition bands.



**Figure 6-2/G.993.1 – Stop-band PSD mask**

The width of the transition bands  $\Delta f_T$  shall be independent of frequency and shall not exceed 175 kHz. Transition bands and values of stop-band PSD below 276 kHz are subject to regional regulations. For some regions, the relevant PSD specifications may be found in Annexes D, E and F.

The corresponding PSD mask values inside the stop-bands shall be as listed in Table 6-1. The values between the points listed in Table 6-1 shall be found using linear interpolation over a linear scale of frequency.

**Table 6-1/G.993.1 – Stop-band PSD mask**

Frequency [MHz]	Maximum PSD [PSD <sub>max</sub> , dBm/Hz]	Maximum power in a 1-MHz sliding window [P <sub>max</sub> , dBm]
<0.276	Subject to regional regulations	—
0.276-4.0	-100	—
4.0-5.0	-100	-50
5.0-30.0	-100	-52
≥30.0	-120	—
Transition frequency	-80	—

The stop-band transmit PSD shall comply with *both* the maximum PSD limitations, using a measurement resolution bandwidth of 10 kHz and the maximum power in a 1-MHz sliding window limitations presented in Table 6-1. The power in a 1-MHz sliding window is measured in a 1-MHz bandwidth starting at frequency  $f_{tr1} + \Delta f_T$  of the corresponding transmit signal band and finishing at the next transition frequency  $f_{tr2} - \Delta f_T$ , as defined in Figure 6-2. If the value of the stop band minus  $2\Delta f_T$ , ( $f_{tr2} - f_{tr1} - 2\Delta f_T$ ), is narrower than 1 MHz, the bandwidth of the measurement device should be set to  $\Delta f_M$ , with  $\Delta f_M$  equal to or less than the value of the stop band minus  $2\Delta f_T$  ( $\Delta f_M \leq f_{tr2} - f_{tr1} - 2\Delta f_T$ ), and the measured result should be recalculated to the 1-MHz sliding window as:

$$P_{\max} = P - 10 \log(\Delta f_M)$$

where  $P$  is the measured result in dBm,  $\Delta f_M$  is the bandwidth used for the measurement in MHz.

### 6.2.3 PSD reduction function in the frequency region below 1.104 MHz

The implementation of the PSD reduction function in the frequency region below 1.104 MHz is mandatory, and the operator determines whether the function is used or not. The exact PSD reduction function for some regions are presented in Annexes D, E and F.

The use of the PSD reduction function shall be selected through G.994.1 (see 12.1 and 12.2).

### 6.2.4 Egress control

G.993.1 equipment shall be able to reduce the PSD below  $-80$  dBm/Hz in one or more of the standardized amateur radio bands simultaneously.  $-80$  dBm/Hz is applied to maximum PSD. The bands to be notched are defined in Table 6-2, which includes the amateur radio frequencies for all regions (Regions 1, 2 and 3; see Figure II.1) described in Table II.1.

**Table 6-2/G.993.1 – Transmit notch bands**

Band start [kHz]	Band stop [kHz]
1 800	2 000
3 500	4 000
7 000	7 300
10 100	10 150
14 000	14 350
18 068	18 168
21 000	21 450
24 890	24 990
28 000	29 700

## 6.3 Upstream Power Back-Off (UPBO)

### 6.3.1 Power back-off mechanism

Upstream Power Back-Off (UPBO) shall be applied to provide spectral compatibility between loops of different lengths deployed in the same binder. Only one UPBO mode shall be supported as described below.

- It shall be possible for the network management system to set the limiting transmit PSD mask,  $PSD_0$ , for the VTU-R to one of the standard transmit PSD masks defined in 6.2.1.



- The VTU-R shall perform UPBO as described in 6.3.2 autonomously, i.e., without sending any significant information to the VTU-O until the UPBO is applied.
- After UPBO has been applied, the VTU-O shall be capable of adjusting the transmit PSD selected by the VTU-R; the adjusted transmit PSD shall be subject to the limitations given in 6.3.2.
- To enable the VTU-R to initiate a connection with the VTU-O, which will occur before UPBO has been applied, the VTU-R shall be allowed to cause more degradation to other loops than expected when using the mode described in 6.3.2.

### 6.3.2 Power back-off mask

The VTU-R shall explicitly estimate the electrical length of its line,  $kl_0$ , and use this value to calculate the transmit PSD mask  $TxPSD(kl_0, f)$ . The VTU-R shall then adapt its transmit signal to conform strictly to the mask  $TxPSD(kl_0, f)$  while remaining below the  $PSD_0$  limit set by the management system as described above. Given:

$$TxPSD(kl_0, f) = PSDREF(f) + (LOSS(kl_0, f) \text{ in dB})$$

$$LOSS = kl_0 \sqrt{f} \text{ in dB}$$

The  $LOSS$  function is an approximation of the loop attenuation (loss).

$PSDREF(f)$  is a function of frequency but is independent of length and type of loop.  $PSDREF(f)$  is of the form  $-a-b\sqrt{f}$ . The values of  $a$  and  $b$  for  $PSD\_REF$  depend on the geographic region and for some regions are presented in Annexes D, E and F.

If the estimated value of  $kl_0$  is smaller than 1.8, the modem shall be allowed to perform power back-off as if  $kl_0$  was equal to 1.8.

The estimate of the electrical length should be sufficiently accurate to avoid spectrum management problems and additional performance loss.

NOTE 1 – A possible estimation of  $kl_0$  is as  $\min[loss(f)/\sqrt{f}]$ . The minimum is taken over the usable VDSL frequency band above 1 MHz. The function  $loss$  is the insertion loss in dB of the loop at frequency  $f$ . This definition is abstract, implying an infinitely fine grid of frequencies. Elsewhere, practical measurements will be specified with a finite frequency grid.

NOTE 2 – To meet network-specific requirements, network management may set parameters  $a$  and  $b$  in  $PSDREF(f)$  and also provide a means to override the modem's autonomous estimate of  $kl_0$ .

### 6.4 Termination impedance

A termination impedance of  $R_T$ , purely resistive, shall be used over the entire VDSL frequency band for both the LT and NT transceivers when matching to the metallic access wire-pair (either source or load). In particular, it shall be used as a termination for the transmit PSD and power definition and verification.

This termination impedance approximates (and is based upon) the insertion-point impedance of the VDSL test loop. It enables a compromise high-frequency impedance match to the various types of unshielded cable in metallic access networks.

The value of  $R_T$  is regionally specific. For some regions the value of  $R_T$  is presented in Annexes D, E and F.

## 6.5 Return loss

The return loss requirement is defined to limit signal power uncertainties due to the tolerance of the line interface impedance. The return loss specifies the amount of reflected differential signal upon a reference impedance  $R_V$ :

$$RL = 20 \log_{10} \left| \frac{Z + R_V}{Z - R_V} \right|, [\text{dB}]$$

where  $Z$  is the internal impedance of the VTU.

The in-band return loss value of the VDSL transceiver shall be greater than or equal to 12 dB. The out-of-band return loss value shall be greater than or equal to 3 dB. In-band and out-of-band frequencies for each transmit direction are defined by the frequency plan as shown in 6.1. The value of 12 dB assumes a flat transmit PSD is applied over the entire in-band region. Requirements may be relaxed in the frequency ranges of reduced PSD values.

The return loss shall be measured on a resistive test load of  $R_V$  while the tested implementation of the VDSL transceiver is powered.

If a service splitter is used, the return-loss requirements shall be met for the full range of possible values of the POTS/ISDN port termination.

## 6.6 Output signal balance

Output Signal Balance (OSB) is a measure of unwanted longitudinal signals at the output of the transceiver. The longitudinal output voltage ( $V_{cm}$ ) to the differential output voltage ( $V_{diff}$ ) ratio shall be measured while the VTU transmitter is active in accordance with ITU-T Recs G.117 and O.9.

$$OSB = 20 \log_{10} \left| \frac{V_{diff}}{V_{cm}} \right|, [\text{dB}]$$

The OSB of the VDSL transceiver shall be equal to or greater than 35 dB in the entire VDSL band. The termination impedance of the transceiver for OSB measurement shall be  $R_V$ .

NOTE – The equipment balance should be better than the anticipated cable balance in order to minimize the unwanted emissions and susceptibility to external RFI. The typical worst-case balance for an aerial drop-wire has been observed to be in the range of 30-35 dB; therefore, the balance of the VDSL equipment should be equal or better.

## 7 TPS-TC sublayer general functional characteristics

The physical layer shall be able to transport at least one of ATM or PTM signals. See Annexes G and H for the specifics of these TPS-TC applications.

### 7.1 $\alpha/\beta$ interface specification

The  $\alpha$  and  $\beta$  reference points define corresponding interfaces between the TPS-TC and PMS-TC at the VTU-O and VTU-R sides, respectively. Both interfaces are hypothetical, application-independent, identical. The interfaces comprise the following flows of signals between the TPS-TC and the PMS-TC sublayers:

- data flow;
- synchronization flow.

NOTE – If dual latency is applied, the interface comprises two identical Data and Synchronization flows: one for the Fast and one for the Slow channel, respectively. Each flow is between the corresponding TPS-TC and PMS-TC sublayer.



### 7.1.1 Data flow

Data flow comprise two generic *octet-oriented* streams with the rates defined by the physical net capabilities:

- transmit data stream: Tx;
- receive data stream: Rx.

The Data flow signals description is presented in Table 7-1.

If data streams are *serial* by implementation, the MSB of each octet shall be sent first. The Tx, Rx data rate values are set during the system configuration.

**Table 7-1/G.993.1 – TPS-TC:  $\alpha/\beta$  interface data and synchronization flows signal summary**

Signal(s)	Description	Direction	Notes
<i>Data signals</i>			
Tx	Transmit data	TPS-TC $\rightarrow$ PMS-TC	
Rx	Receive data	TPS-TC $\leftarrow$ PMS-TC	
<i>Synchronization signals</i>			
Clk <sub>t</sub>	Transmit bit timing	TPS-TC $\leftarrow$ PMS-TC	Optional
Clk <sub>r</sub>	Receive bit timing		
Osync <sub>t</sub>	Transmit octet timing		
Osync <sub>r</sub>	Receive octet timing		

### 7.1.2 Synchronization flow

This flow provides synchronization between the TPS-TC sublayer and PMS-TC sublayer. The Synchronization flow comprises up to four synchronization signals presented in Table 7-2:

- transmit and receive data flow bit-synchronization (Clk<sub>t</sub>, Clk<sub>r</sub>);
- transmit and receive data flow octet-synchronization (Osync<sub>t</sub>, Osync<sub>r</sub>).

All synchronization signals are asserted by PMS-TC and directed towards TPS-TC. The signals Osync<sub>t</sub>, Osync<sub>r</sub> are mandatory; other signals are *optional*.

The Clk<sub>t</sub> and the Clk<sub>r</sub> rates are matched with the Tx and the Rx data rates, respectively.

## 7.2 OC TPS-TC application interface ( $\gamma_O$ , $\gamma_R$ ) description

This clause specifies a VDSL Operations Channel Transport Protocol Specific Transmission Convergence sublayer (OC-TC), which describes the transmission of the Embedded Operations Channel (eoc) over a VDSL link between the VDSL Management Entities (VME) at the opposite sides of the link (see Figure 10-2). The OC-TC is specified at both the  $\gamma_O$  and  $\gamma_R$  reference points of the VTU-O and VTU-R sites, respectively. Both  $\gamma$  interfaces are functional, identical and contain the following flows of signals:

- data flow;
- synchronization flow.

### 7.2.1 Data flow

The eoc data flow includes two contra-directional streams of 2-octet blocks each (eoc\_tx, eoc\_rx) with independent rates flowing between the eoc application layer (VME) and TPS-TC OC block (OC-TC). The bit rates of both streams shall not exceed the predefined upper limit of the OC channel aggregate transport capability. The data flow signal description is presented in Table 7-1.

If data streams are *serial* by implementation, the MSB of each octet shall be sent first.

### 7.2.2 Synchronization flow

This flow provides synchronization between the eoc application layer (VME) and the OC-TC (see 10.3.1). The flow includes the following synchronization signals, presented in Table 7-2:

- transmit and receive timing signals (eoc\_tx\_clk, eoc\_rx\_clk): both asserted by the eoc processor;
- transmit enable flag (tx\_enbl): asserted by OC-TC and allows to transmit the next 2-octet block;
- receive enable flag (rx\_enbl): asserted by OC-TC and indicates that the next 2-octet block is allocated in the OC-TC receive buffer.

**Table 7-2/G.993.1 – OC-TC:  $\gamma$  interface data and synchronization flow summary**

Signal	Description	Direction	Notes
<i>Data flow</i>			
eoc_tx	Transmit eoc data	VME → OC-TC	Two-octet block
eoc_rx	Receive eoc data	VME ← OC-TC	
<i>Synchronization flow</i>			
eoc_tx_clk	Transmit clock	VME → OC-TC	
eoc_rx_clk	Receive clock	VME → OC-TC	
tx_enbl	Transmit enable flag	VME ← OC-TC	
rx_enbl	Receive enable flag	VME ← OC-TC	

NOTE – The main buffering required to implement the eoc communication protocol should be provided by the VME; only a minimum buffering for eoc is supposed in OC-TC.

## 8 PMS-TC sublayer

The PMS-TC sublayer provides transmission medium specific TC functions, such as framing, Forward Error Correction (FEC), and interleaving.

### 8.1 PMS-TC functional model

All data bytes shall be transmitted MSB first. All serial processing (e.g., scrambling, CRC calculation) shall however be performed LSB first, with the outside world MSB considered as the VDSL LSB. As a result, the first incoming bit (outside world MSB) shall be the first bit processed inside VDSL (VDSL LSB). The PMS-TC functional diagram is presented in Figure 8-1.

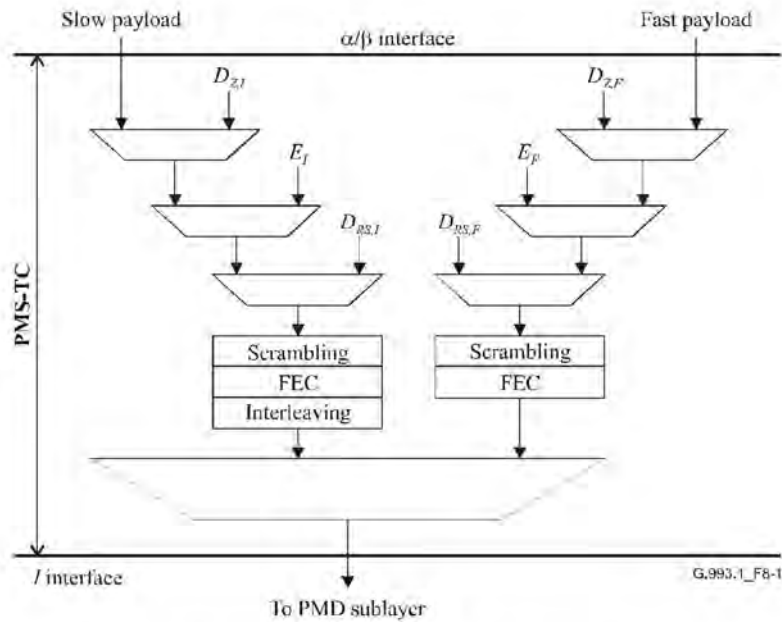


Figure 8-1/G.993.1 – Diagram of PMS-TC sublayer

## 8.2 Scrambler

A scrambler shall be used to reduce the likelihood that a long sequence of zeros will be transmitted over the channel. The scrambler shall be self-synchronizing such that descrambling can occur without requiring a particular alignment with the scrambled sequence. The scrambler shall be represented by the equation below, where  $m(n)$  is a message bit sample at sample time  $n$  and the output of the scrambler  $x(n)$  shall be given by:

$$x(n) = m(n) + x(n-18) + x(n-23)$$

All arithmetic shall be modulo 2. As long as the scrambler is initialized with values other than zero, an "all zeros" sequence for  $m(n)$  will result in a pseudo-random sequence of length  $2^{23} - 1$ .

## 8.3 Forward error correction

A standard byte-oriented Reed-Solomon code shall be used to provide protection against random and burst errors.

A Reed-Solomon code word contains  $N = K + R$  bytes, comprised of  $R$  redundant check bytes  $c_0, c_1, \dots, c_{R-2}, c_{R-1}$  appended to  $K$  message bytes  $m_0, m_1, \dots, m_{K-2}, m_{K-1}$ . The check bytes shall be computed from the message bytes using the equation

$$C(D) = M(D)D^R \bmod G(D)$$

where:

$$M(D) = m_0 D^{K-1} \oplus m_1 D^{K-2} \oplus \dots \oplus m_{K-2} D \oplus m_{K-1} \text{ is the message polynomial}$$

$$C(D) = c_0 D^{R-1} \oplus c_1 D^{R-2} \oplus \dots \oplus c_{R-2} D \oplus c_{R-1} \text{ is the check polynomial}$$

$$G(D) = \prod (D \oplus \alpha^i) \text{ is the generator polynomial of the Reed-Solomon code, where the index of the product runs from } i = 0 \text{ to } R - 1.$$

This means that  $C(D)$  is the remainder obtained from dividing  $M(D)D^R$  by  $G(D)$ . The arithmetic shall be performed in the Galois Field GF(256), where  $\alpha$  is a primitive element that satisfies the



primitive binary polynomial  $x^8 \oplus x^4 \oplus x^3 \oplus x^2 \oplus 1$ . A data byte  $(d_7, d_6, \dots, d_1, d_0)$  is identified with the Galois Field element  $d_7\alpha^7 \oplus d_6\alpha^6 \oplus \dots \oplus d_1\alpha \oplus d_0$ .

Both  $K$  and  $R$  shall be programmable parameters. Redundancy values of  $R = 0, 2, 4, 6, 8 \dots 16$  shall be supported. The following codeword parameters specified as  $(N, K)$  shall be supported: (144,128) and (240,224). Other values for  $N$  and  $K$  are optional. However,  $N$  shall be less than or equal to 255.

## 8.4 Interleaving

### 8.4.1 General

Interleaving shall be used to protect the data against bursts of errors by spreading the errors over a number of Reed-Solomon codewords. The interleave depth shall be programmable with a maximum interleave depth of 64 codewords when the number of octets per codeword ( $N$ ) equals 255. For smaller values of  $N$  the interleave depth can grow nearly proportionately.

It shall be possible to adjust the interleave depth via the management system to meet latency requirements. The latency of the slow path is a function of the data rate and burst error correction capability. For data rates greater than or equal to 13 Mbit/s, the latency between the  $\alpha$  and  $\beta$  interfaces shall not exceed 10 ms when the interleaver depth is set to the maximum. At lower data rates there is a trade-off between higher latency and decreased burst error correction ability. At any data rate, the minimum latency occurs when the interleaver is turned off.

When the interleaver is on, the codewords shall be interleaved before transmission to increase the immunity of RS codewords to bursts of errors. The convolutional interleaver is defined by two parameters: the interleaver block length,  $I$ , and the interleaving depth,  $D$ . The block length  $I$  shall divide the RS codeword length  $N$  (i.e.,  $N$  shall be an integer multiple of  $I$ ). The convolutional interleaver uses a memory in which a block of  $I$  octets is written while an (interleaved) block of  $I$  octets is read. Details of the implementation are given in 8.4.2.

The same size interleaving memory (see Table 8-1) is needed for interleaving at the transmitter and de-interleaving at the receiver.

The convolutional interleaving introduces an absolute read-to-write delay,  $\Delta_j$ , that increments linearly with the octet index within a block of  $I$  octets:

$$\Delta_j = (D-1) \times j$$

where  $j = 0, 1, 2, \dots, I-1$ .

### 8.4.2 Triangular implementation

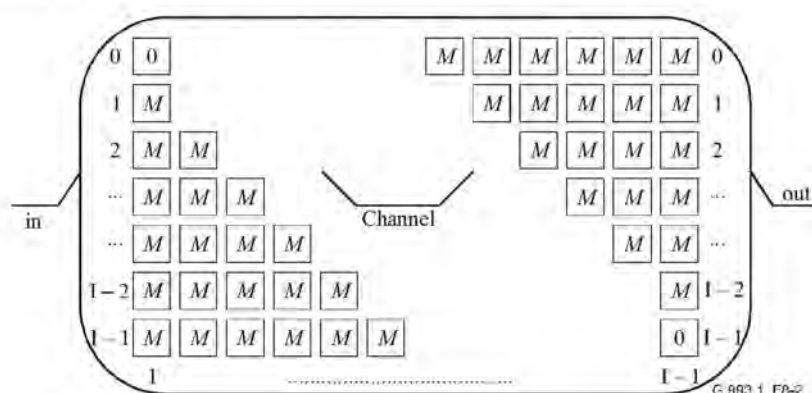
To decrease the implementation complexity, the delay increment  $(D-1)$  shall be chosen as a multiple of the interleaver block length ( $I$ ), i.e.:  $D-1 = M \times I$ . The  $(D-1)$  to  $I$  ratio is the interleaving depth parameter ( $M$ ). The characteristics of convolutional interleaving are shown in Table 8-1. The parameters  $t$  and  $q$  depend on the characteristics of the RS code and are defined as:

- $t$  = number of bytes that can be corrected by RS codewords = half the number of redundancy bytes =  $R/2$ ;
- $q$  = length of RS codeword divided by the length of an interleaver block =  $N/I$ .

**Table 8-1/G.993.1 – Characteristics of convolutional interleaving**

Parameter	Value
Interleaver block length ( $I$ )	$I$ bytes (equal to or divisor of $N$ )
Interleaving Depth ( $D$ )	$M \times I + 1$
(De)interleaver memory size	$M \times I \times (I - 1)/2$ bytes
Correction capability	$\lfloor t/q \rfloor \times (M \times I + 1)$ bytes
End-to-end delay	$M \times I \times (I - 1)$ bytes

The example in Figure 8-2 shows  $I = 7$ .  $I$  parallel branches (numbered  $0 \dots I - 1$ ) are implemented with a delay increment of  $M$  octets per branch. Each branch shall be a FIFO shift register (delay line) with length  $0 \times M \dots (I - 1) \times M$  bytes. The deinterleaver is similar to the interleaver, but the branch indices are reversed so that the largest interleaver delay corresponds to the smallest deinterleaver delay. Deinterleaver synchronization shall be achieved by routing the first byte of an interleaved block of  $I$  bytes into branch 0.

**Figure 8-2/G.993.1 – Implementation example with  $D - 1 = M \times I$  and  $I = 7$** **Table 8-2/G.993.1 – Example of interleaver parameters with RS(144,128)**

Rate [kbit/s]	Interleaver parameters	Interleaver depth	(De)interleaver memory size	Erasure correction	End-to-end delay
$50 \times 1024$	$I = 72$ $M = 13$	937 blocks of 72 bytes	33 228 bytes	3 748 bytes 520 $\mu$ s	9.23 ms
$24 \times 1024$	$I = 36$ $M = 24$	865 blocks of 36 bytes	15 120 bytes	1 730 bytes 500 $\mu$ s	8.75 ms
$12 \times 1024$	$I = 36$ $M = 12$	433 blocks of 36 bytes	7 560 bytes	866 bytes 501 $\mu$ s	8.75 ms
$6 \times 1024$	$I = 18$ $M = 24$	433 blocks of 18 bytes	3 672 bytes	433 bytes 501 $\mu$ s	8.5 ms
$4 \times 1024$	$I = 18$ $M = 16$	289 blocks of 18 bytes	2 448 bytes	289 bytes 501 $\mu$ s	8.5 ms
$2 \times 1024$	$I = 18$ $M = 8$	145 blocks of 18 bytes	1 224 bytes	145 bytes 503 $\mu$ s	8.5 ms



The following interleaver parameters shall be supported:

- For  $(N,K) = (144,128)$  the following values for  $M$  and  $I$  shall be supported:  
 $I = 36$  and  $M$  between 2 and 52.
- For  $(N,K) = (240,224)$  the following values for  $M$  and  $I$  shall be supported:  
 $I = 30$  and  $M$  between 2 and 62.

## 8.5 Framing

### 8.5.1 Frame description

A *frame* is a set of bytes carried by one DMT symbol. The frame frequency depends on the total length of the cyclic extension (see 9.2.2). A frame shall be composed of two sources: the "fast" buffer and the "interleaved" (or "slow") buffer. The index  $i$  refers to parameters related to the fast or interleaved buffers ( $i \in \{F, I\}$ ). The inclusion of the fast buffer shall be optional. When the fast buffer is not included, the interleaved buffer shall have the capability to carry non-interleaved data by setting the interleaver depth to zero.

Both fast and interleaved buffer shall contain an integer number of RS-encoded bytes. Neither the fast nor the interleaved buffer is required to carry an integer number of RS codewords. To reduce the end-to-end delay, it is recommended that the fast buffer (or the interleaved buffer when the interleaver depth is zero) carries at least one RS codeword. The framing parameters shall be exchanged between the VTU-O and VTU-R during initialization.

The framing rules described in this clause are represented in Figure 8-3.

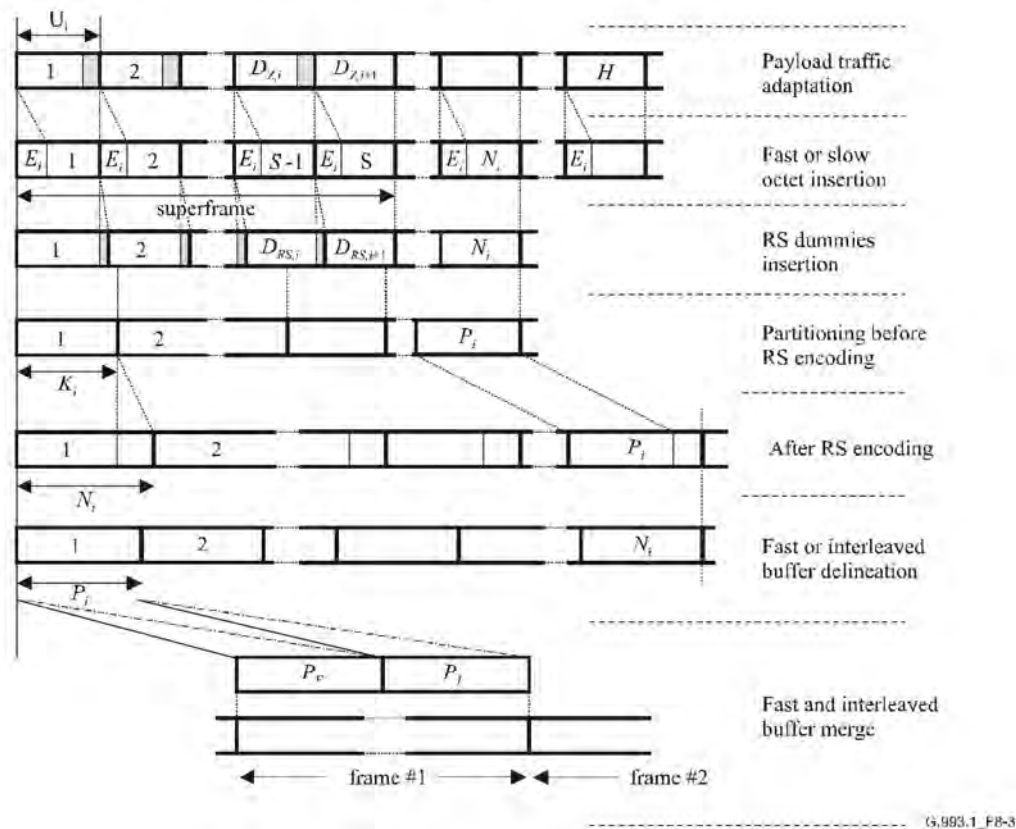


Figure 8-3/G.993.1 – Framing description

### 8.5.2 Payload adaptation

The  $\alpha/\beta$  interface provides bytes at a rate multiple of 64 kbit/s. In order to map an integer number of bytes into a frame, the TPS-TC byte flow shall be stuffed with the appropriate number of dummies.

For an  $n_i \times 64$  kbit/s rate, we have on average  $n_i \times 8000/f_s$  bytes per frame, with  $f_s$  the symbol frequency. This number will not be integer for a general value of  $f_s$ . Since the cyclic extension  $L_{CP} + L_{CS} - \beta$  is a multiple of  $2^{n+1}$  however, (see 9.2.2), we always have an integer number of bytes every  $H = 138$  frames. If we define  $k$  as:

$$k = \frac{8 \text{ kbytes} \times H}{f_s}$$

we can transport  $n_i \times k$  TPS-TC payload bytes in  $H$  frames. In order to transport an integer number of bytes per frame, we have to insert an appropriate number of dummy bytes. Every frame will contain a total of  $U_i$  bytes (TPS-TC bytes + dummy bytes), with:

$$U_i = \left\lceil \frac{n_i \times k}{H} \right\rceil$$

The number of dummy bytes  $D_{Z,i}$  to be inserted every  $H$  packets shall therefore be:

$$D_{Z,i} = \left\lceil \frac{n_i \times k}{H} \right\rceil \times H - (n_i \times k)$$

These dummy bytes shall be inserted in the last position of the first  $D_{Z,i}$  packets of  $U_i$  bytes in a sequence of  $H$  packets. The value of the  $D_{Z,i}$  dummies shall be 0x3A.

### 8.5.3 RS encoding

After payload adaptation,  $E_i$  overhead bytes (see 8.5.5) shall be added to the head-end of each packet of  $U_i$  bytes (see Figure 8-3). These bytes are called fast and slow bytes for the fast and slow channel respectively. Next, a sequence of  $N_i$  packets of  $(E_i + U_i)$  bytes shall be RS-encoded. In order to achieve an integer number of RS-codewords per  $N_i$  packets, RS-dummy bytes may have to be inserted. The RS-codeword length is equal to the parameter  $N_i$ .

The number of RS-encoded bytes,  $B_i$ , per  $N_i$  packets is given by:

$$B_i = \left\lceil N_i \times (E_i + U_i) + D_{RS,i} \right\rceil \times \frac{N_i}{K_i}$$

In the above equation, the parameter  $N_i$  denotes both the number of packets of  $(E_i + U_i)$  bytes and also the length of a RS-codeword (in bytes). The parameter  $K_i$  is the number of information bytes in an RS-codeword.

The number of RS dummy bytes,  $D_{RS,i}$ , inserted to carry an integer number of RS-codewords in every  $N_i$  frames is given by

$$D_{RS,i} = \left\lceil \frac{N_i \times (E_i + U_i)}{K_i} \right\rceil \times K_i - N_i \times (E_i + U_i)$$

Each one of the  $D_{RS,i}$  dummies shall be inserted at the tail-end of the first  $D_{RS,i}$  packets of  $(E_i + U_i)$  bytes in a sequence of  $N_i$  packets (see Figure 8-3). The value of the  $D_{RS,i}$  bytes shall be 0xD3.

After RS-dummy insertion, the number of RS-encoded bytes per frame carried in either the fast or interleaved buffer is given by:

$$P_i = \frac{B_i}{N_i} = \frac{N_i \times (E_i + U_i) + D_{RS,i}}{K_i} = \left\lceil \frac{N_i \times (E_i + U_i)}{K_i} \right\rceil$$



NOTE – The parameter  $B_i = P_i N_i$  represents both the number of bytes in  $N_i$  frames (with  $P_i$  bytes per frame) and also the number of bytes in  $P_i$  codewords (with  $N_i$  bytes per codeword). See Figure 8-3.

#### 8.5.4 Definition of superframe

A superframe shall be composed of 10 packets of  $U_i + E_i$  bytes.

#### 8.5.5 Contents of fast and slow bytes

Each of the packets in a superframe shall transport  $E_i$  overhead bytes, called fast or slow bytes, depending on the channel. The content of these bytes is summarized in Table 8-3. If the fast buffer is empty, the F-EOC bytes shall be transported in the S-EOC bytes. Otherwise, the S-EOC bytes shall be replaced with payload bytes.

There shall be  $V$  VOC bytes per packet. They shall always be transported in the slow channel. A setting of  $V = 1$  shall be supported, other values for  $V$  should be allowed as optional. The value of  $V$  shall be exchanged during initialization (see 12.4.6.2.1.1).

If the fast path is active, the NTR byte in the slow channel shall be replaced with a dummy byte. Similarly for the IB bytes.

The fast and slow dummy bytes shall have the value 0xFF.

**Table 8-3/G.993.1 – Contents of fast and slow bytes**

Packet	Fast bytes		Slow bytes		
	First byte	Other bytes (if any)	First byte	2nd up to $(V+1)$ st byte	Other bytes (if any)
1	F-CRC	F-EOC	S-CRC	VOC	S-EOC/payload
2	Synch byte	F-EOC	Synch byte	VOC	S-EOC/payload
3-5	IB	F-EOC	IB/dummy	VOC	S-EOC/payload
6	NTR	F-EOC	NTR/dummy	VOC	S-EOC/payload
7-10	Dummy	F-EOC	Dummy	VOC	S-EOC/payload

##### 8.5.5.1 Cyclic Redundancy Check (CRC)

Two cyclic redundancy checks (CRC) – one for the fast buffer and one for the interleaved buffer – shall be generated for each superframe and shall be transmitted in the first packet of the following superframe (see Table 8-3). The CRC byte for the first superframe shall be set to zero.

Eight bits per buffer type (fast or interleaved) and per superframe shall be allocated to the CRC check bits. These bits shall be computed from the  $k$  message bits using the equation:

$$crc(D) = M(D) D^8 \text{ modulo } G(D)$$

where:

$M(D) = m_0 D^{k-1} + m_1 D^{k-2} + \dots + m_{k-2} D + m_{k-1}$  is the message polynomial

$G(D) = D^8 + D^4 + D^3 + D^2 + 1$  is the generating polynomial

$crc(D) = c_0 D^7 + c_1 D^6 + \dots + c_6 D + c_7$  is the check polynomial

$D$  is the delay operator.

That is,  $crc(D)$  shall be the remainder when  $M(D)D^8$  is divided by  $G(D)$ .

The bits covered by the crc shall include:

- fast buffer: all bits of the fast buffer before RS encoding, except the crc;
- interleaved buffer: all bits of the interleaved buffer before RS encoding, except the crc.



Each byte shall be clocked into the CRC least significant bit first.

#### 8.5.5.2 Synchronization byte

The synchronization byte has the value 0x3C. This synchronization byte shall be used to monitor the frame synchronization.

#### 8.5.5.3 Indicator Bits (IB)

The indicator bits are used to transmit far-end defects and anomalies. The description of the content of the three indicator bytes shall be as summarized in Table 8-4. If the fast channel is active, the indicator bytes shall be transmitted in this channel and the indicator bytes in the slow channel shall be replaced by dummies (having value 0xFF, see 8.5.5).

**Table 8-4/G.993.1 – Content of indicator bits**

Byte #	Bit #	Definition
1	b0-b7	Reserved for future use
2	b0	Febe-s
	b1	Ffec-s
	b2	Febe-f
	b3	Ffec-f
	b4	Flos
	b5	Rdi
	b6	Fpo
	b7	Flpr
3	b0	LoM (Loss of Margin)
	b1	Fhec-s (used for ATM only, shall be set to 0 for PTM)
	b2	Fhec-f (used for ATM only, shall be set to 0 for PTM)
	b3	Fncd-s/Focd-s (used for ATM only, shall be set to 0 for PTM)
	b4	Fncd-f/Focd-f (used for ATM only, shall be set to 0 for PTM)
	b5-b7	Reserved for future use

The active state of a bit shall be high (value 1). Bits that are reserved for future use shall be set to low (value 0).

The definition of the anomalies and defects linked to each of the indicator bits can be found in 10.5.4. The LoM-bit shall signal a loss of margin at the far end. It shall become high once loss of margin is detected and shall remain high as long as this condition exists.

#### 8.5.5.4 Network Timing Reference (NTR)

Isochronous services require the same timing reference at transmit and receive sides in higher layers of the protocol stack. To support the transmission of this timing signal, the VDSL system shall transport an 8-kHz timing marker.

For applications that require NTR, NTR shall be transported in the following way:

The VTU-O shall derive a local 8-kHz timing reference (LTR), by dividing its sample clock with the appropriate number. For a VDSL system using  $N_{sc} = 2^{n+8}$  tones, the sampling frequency could for instance be  $2 N_{sc} \Delta f$  and the dividing factor would then be  $69 \times 2^{n+2}$ .

The VTU-O shall estimate the change in phase offset between the NTR and the LTR from the previous superframe to the present. This value shall be expressed in cycles of a clock running at

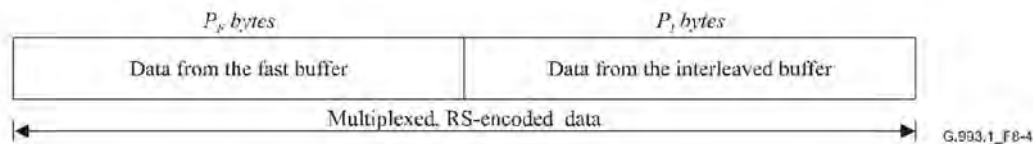
frequency  $2 N_{sc} \Delta f$  and shall be transported in the NTR overhead byte (see Table 8-3) as a 2's-complement number.

A positive value of the change in phase offset shall indicate that the LTR has a higher frequency than the NTR. A negative value of the change in phase offset shall indicate that the LTR has a lower frequency than the NTR.

The LTR, being proportional to  $\Delta f$ , has a maximum frequency variation of 50 ppm (see 9.2.1.1). The NTR has a maximum variation of 32 ppm. The maximum difference is therefore 82 ppm. This would result in a maximal phase offset of  $0.205 \mu\text{s}$  per superframe. This corresponds to about  $0.45 \cdot 2^n$  samples. For the largest value of  $n$  ( $n = 4$ ), this corresponds to somewhat more than 7 samples (in the positive or negative direction). One byte of information should therefore be sufficient.

#### 8.5.6 Convergence of fast and interleaved buffer

Data from the interleaved and (optional) fast buffer shall be combined so that in each frame there shall first be a segment of fast data followed by a segment of interleaved data. Figure 8-4 illustrates this process.



**Figure 8-4/G.993.1 – Convergence of the fast and interleaved data into one frame**

The total number of RS-encoded bytes per frame,  $P_{total}$ , is given by:

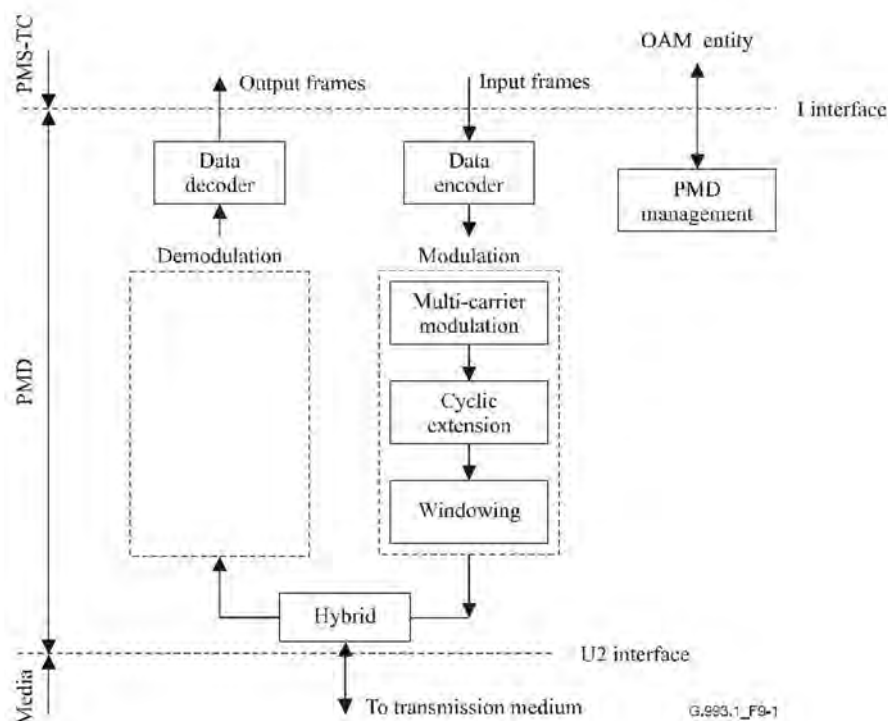
$$P_{total} = P_I + P_F$$

where  $P_I$  and  $P_F$  are the number of RS-encoded bytes from the interleaved and fast paths.

## 9 PMD sublayer

### 9.1 PMD functional model

The functional model of the PMD sublayer is presented in Figure 9-1.



**Figure 9-1/G.993.1 – Functional diagram of PMD sublayer**

In the transmit direction, the PMD layer shall receive input frames from the PMS-TC sublayer. A frame shall contain exactly the number of bytes that will be modulated onto one DMT symbol. This shall be an integer number. Each carrier shall have a number of bits assigned to it during initialization. The bits that are to be modulated on a carrier shall be encoded into constellation points according to the rules given in 9.2.5. After encoding, the carriers shall be modulated and summed using an IDFT. The resulting digital signal shall be cyclically extended and windowed before being sent towards the transmission medium over the U interface.

In the receive direction, the modem shall receive the signal over the U interface and perform the required actions to recover the transmitted signal. The data obtained from the demodulator shall be sent to the data decoder that will extract the output data frames. These data frames shall be sent to the PMS-TC layer over the I interface.

The management block is responsible for all OAM functions relating to the PMD layer.

## 9.2 PMD functional characteristics

### 9.2.1 Multi-carrier modulation

The modulation shall use a maximum number of sub-carriers equal to  $N_{SC} = 2^{n+8}$ , where  $n$  can take the values 0, 1, 2, 3, 4. Disjoint subsets of the  $N_{SC}$  sub-carriers shall be defined for use in the downstream and upstream directions. These subsets are determined by the frequency plan (see 6.1). The exact subsets of sub-carriers used to modulate data in each direction shall be determined during initialization and shall be based on management system settings and the signal-to-noise ratios (SNRs) of the sub-channels. In many cases the number of sub-carriers used in a direction will be less than the maximum number allowed by the partitioning.



### 9.2.1.1 Tone spacing

The frequency spacing,  $\Delta f$ , between the sub-carriers shall be 4.3125 kHz, with a tolerance of 50 ppm. The sub-carriers shall be centred at frequencies  $f = k \Delta f$ . The tone index  $k$  can take the values  $k = 0, 1, 2, \dots, N_{SC} - 1$ .

### 9.2.1.2 Data sub-carriers

Transmission may take place on up to  $N_{SC} - 1$  sub-carriers, since DC is not used. The actual number of sub-carriers used may be lower than this maximum number. The lower limit depends on the presence of amateur radio-frequency bands and the required notching in these bands, the POTS or ISDN splitter, PSD masks, implementation-specific filters and the services to be provided.

### 9.2.1.3 Modulation by the Inverse Discrete Fourier Transform (IDFT)

The encoder shall generate  $N_{SC}$  complex values  $Z_i$  ( $i = 0, \dots, N_{SC} - 1$ ), including the zero at DC because the sub-carrier centred at DC shall not be used for data transmission. To generate real time-domain values  $x_k$  using a complex-to-real IDFT, the set of frequency-domain values  $Z_i$  shall be augmented to generate a new vector  $Z'_i$  of size  $N = 2N_{SC}$ . The vector  $Z'_i$  shall be Hermitian. That is:

$$\begin{aligned} Z'_i &= Z_i, i = 0, \dots, N_{SC} - 1 \\ Z'_i &= \text{conj}(Z_{2N_{SC}-i}), i = N_{SC}, \dots, 2N_{SC} - 1 \end{aligned}$$

The Nyquist frequency shall not be modulated, therefore,  $Z'_i = 0$  for  $i = N_{SC}$ .

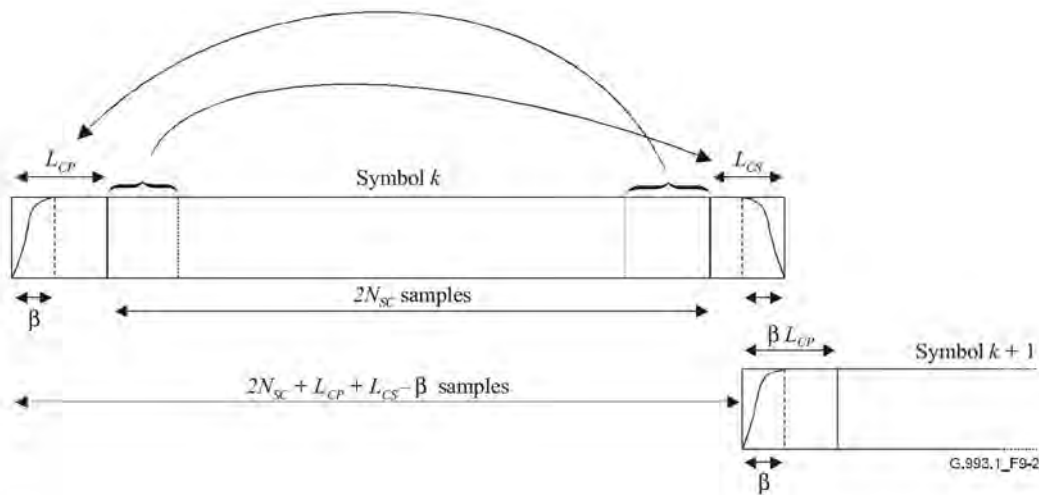
The vector  $Z'_i$  shall be transformed to the time domain by an inverse discrete Fourier transform (IDFT). The modulating transform defines the relationship between the  $2N_{SC}$  real time-domain values  $x_k$  and the  $2N_{SC}$  complex numbers  $Z'_i$ :

$$x_k = \sum_{i=0}^{2N_{SC}-1} Z'_i e^{j \frac{2\pi k i}{2N_{SC}}}, \quad k = 0, \dots, 2N_{SC} - 1$$

### 9.2.2 Cyclic extension

The last  $L_{CP}$  samples of the IDFT output  $x_k$  shall be prepended to the  $2N_{SC}$  time-domain samples  $x_k$  as the cyclic prefix. The first  $L_{CS}$  samples of  $x_k$  shall be appended to the block of time-domain samples as the cyclic suffix.

The first  $\beta$  samples of the prefix and last  $\beta$  samples of the suffix shall be used for shaping the envelope of the transmitted signal. The maximal value of  $\beta$  shall be  $16 \times 2^n$ , but not more than 255. The windowed parts of consecutive symbols shall overlap ( $\beta$  samples). Figure 9-2 summarizes all the operations that have to be performed and illustrates the relationship between the various parameters.



**Figure 9-2/G.993.1 – Cyclic extensions, windowing and overlap of DMT symbols**

The total cyclic extension is defined as  $L_{CE} = L_{CP} + L_{CS} - \beta$ . The values  $L_{CP}$ ,  $L_{CS}$  and  $\beta$  shall be chosen in order to satisfy the equation  $(L_{CP} + L_{CS} - \beta) = m \times 2^{n+1}$ , where  $m$  shall be an integer value.  $L_{CP}$ ,  $L_{CS}$  and  $\beta$  shall be chosen such that  $L_{CP} + L_{CS} - \beta$  can at least take the value  $40 \times 2^n$ . Other values should be allowed as optional.

In all cases, the following relations shall hold:  $\beta < L_{CP}$  and  $\beta < L_{CS}$ .

In synchronous mode of operation (see 9.2.3.4), the size of the non-windowed part of the suffix shall be the same for all modem pairs in a binder group and its duration shall be equal to the propagation delay (one way) of the longest line in the binder. In synchronous operation, VTU-Os and VTU-Rs operating in the same binder shall have a common frame clock. All transceivers shall start transmission of DMT frames at the same time.

Table 9-1 lists the number of samples in the cyclic extension as a function of the maximum number of sub-carriers, for the case  $L_{CE} = 40 \times 2^n$ . In selecting these values, each DMT symbol has a duration of 250  $\mu$ s, irrespective of the sampling rate. This results in a 4-kHz symbol rate.

**Table 9-1/G.993.1 – Selection of cyclic extension as function of the number of sub-carriers to achieve a 4-kHz symbol rate**

Cyclic extension (samples)	Maximum of sub-carriers $N_{SC}$
40	256
80	512
160	1024
320	2048
640	4096

For a given choice of the cyclic extensions and windowing length  $\beta$ , the symbols will be transmitted at a symbol rate equal to:

$$f_s = \frac{2N_{SC} \times \Delta f}{2N_{SC} + L_{CP} + L_{CS} - \beta}$$



### 9.2.3 Synchronization

#### 9.2.3.1 Pilot tones

Use of dedicated pilot tones shall be optional. During initialization, the VTU-R shall select a sub-channel to use for timing recovery. The VTU-R may require a dedicated pilot tone on which data shall not be transmitted, or it may be capable of performing timing recovery using sub-channels that support data. If the VTU-R requires a dedicated pilot tone, it shall indicate its choice of pilot tone to the VTU-O during initialization (see 12.4.6.3.1.4). The VTU-O shall then transmit the 4QAM value of 00 on that tone during every symbol.

#### 9.2.3.2 Loop timing

The VTU-R shall loop time its local sampling clock to the pilot selected during initialization.

#### 9.2.3.3 Timing advance

The VTU-R shall be capable of implementing a timing offset called Timing Advance (TA) in the transmission of DMT symbols. The TA forces the VTU-O/VTU-R pair to start transmissions of frames in opposite directions simultaneously (i.e., the frames in downstream and upstream transmission direction start at the same (absolute) time). The timing advance shall be equal to the propagation delay from the VTU-O to the VTU-R. It shall be calculated during initialization. The TA is subtracted from the received symbol start time, and the result shall be used as the VTU-R's individual symbol start time so that both the VTU-O and VTU-R transmitters start transmitting each DMT frame at the same time. This is illustrated in Figure 9-3.

NOTE – The timing advance should apply at the U2 interface to obtain the desired orthogonality between transmit and receive signals.

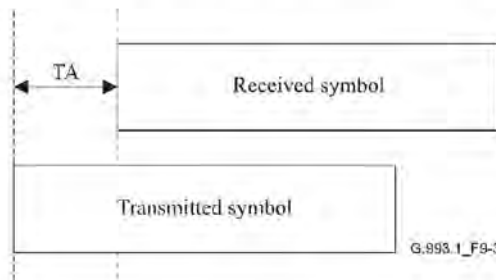


Figure 9-3/G.993.1 – Illustration of Timing Advance (TA)

#### 9.2.3.4 Synchronous mode (optional)

In synchronous mode, all VTU-O transceivers in the same cable binder shall transmit with respect to a common symbol clock, and thus start the transmission of DMT symbols at the same time. The symbol clock, which may be derived from a reference clock, shall be phase synchronous at all VTU-Os in a shared cable with a 1  $\mu$ s maximum phase error tolerance. The VTU-R shall extract the symbol clock from the received data. Timing advance (see 9.2.3.3) shall be used to correct the VTU-R symbol timing to synchronize VTU-O and VTU-R transmissions.

In synchronous mode, near-end crosstalk (NEXT) due to other (synchronized) VDSL systems will be orthogonal to the desired useful signal and hence not interfere with the useful received signal.

### 9.2.4 Power back-off in the upstream direction

To mitigate the effects of FEXT from short lines into long lines in distributed cable topologies, upstream power back-off shall be applied. Transceivers shall be capable of performing frequency-dependent power back-off.

The mechanism for power back-off shall comply with the procedure specified in 6.3. This shall be implemented as described below.

The PBO method is defined by a reference PSD (PSD\_REF) at the VTU-O. This reference PSD shall be input via the management interface and shall be transmitted from the VTU-O to the VTU-R (see 12.4.4.2.1.1).

The VTU-R shall estimate the insertion losses of the upstream bands based on the received downstream signals. From this, the shape of the LOSS function (or, equivalently, the electrical length) as defined in 6.3.2 shall be derived. The VTU-R shall then compute the transmit PSD by dividing the reference PSD in the upstream bands by the estimated LOSS function. Next, the VTU-R shall take a tone-by-tone minimum of this computed PSD and the maximum allowed transmit PSD in the upstream direction. The result shall be used as the initial upstream transmit PSD. The PSD received by the VTU-O should approximate the reference PSD. Upon receiving signals from the VTU-R, the VTU-O shall compare the actual received PSD to the reference PSD. If necessary, it shall instruct the VTU-R to fine-tune its PSD (under the requirements of 6.3.2).

The VTU-O shall also have the capability to directly impose a maximum allowed transmit PSD at the VTU-R. This maximum transmit PSD shall also be input via the management interface and shall be transmitted from VTU-O to VTU-R in the early stages of the initialization. The VTU-O shall allow the operator to select one of these two methods. If the PBO is defined as a maximum transmit PSD at the VTU-R, the VTU-R shall adjust its transmit PSD such that it does not exceed the maximum allowed transmit PSD. The restrictions specified in 6.3.2 shall also apply in this case (i.e., the VTU-O shall not impose a transmit PSD mask that violates the mask specified there).

### 9.2.5 Constellation encoder

An algorithmic constellation encoder shall be used to construct sub-channel QAM constellations with a minimum number of bits equal to 1. The maximum number of bits that shall be supported is negotiated during initialization. The maximum number in the downstream direction shall be  $B_{max\_d}$ ; the maximum number in the upstream direction shall be as  $B_{max\_u}$ . The values of  $B_{max\_d}$  and  $B_{max\_u}$  shall be exchanged during initialization (see 12.4.6.2.1.1 and 12.4.6.3.1.1) and shall be constrained by:

$$8 \leq B_{max\_d} \leq 15$$

and:

$$8 \leq B_{max\_u} \leq 15$$

For a given sub-channel, the encoder shall select an odd-integer point  $(X,Y)$  from the square-grid constellation based on the  $b$  bits  $\{v_{b-1}, v_{b-2}, \dots, v_1, v_0\}$ . For convenience of description, these  $b$  bits shall be identified with an integer label whose binary representation is  $(v_{b-1}, v_{b-2}, \dots, v_1, v_0)$ . For example, for  $b = 2$ , the four constellation points shall be labelled 0, 1, 2, and 3 corresponding to  $(v_1, v_0) = (0,0), (0,1), (1,0),$  and  $(1,1)$ , respectively.

#### 9.2.5.1 Even values of $b$

For even values of  $b$ , the integer values  $X$  and  $Y$  of the constellation point  $(X,Y)$  shall be determined from the  $b$  bits  $\{v_{b-1}, v_{b-2}, \dots, v_1, v_0\}$  as follows.  $X$  and  $Y$  shall be the odd integers with two's-complement binary representations  $(v_{b-1}, v_{b-3}, \dots, v_1, 1)$  and  $(v_{b-2}, v_{b-4}, \dots, v_0, 1)$ , respectively. These values require appropriate scaling such that, at the output of the constellation mapper, all constellations regardless of size represent the same RMS energy as a subcarrier transmitted at a level equal to the PSD template. The most significant bits (MSBs),  $v_{b-1}$  and  $v_{b-2}$ , shall be the sign bits for  $X$  and  $Y$ , respectively. Figure 9-4 shows example constellations for  $b = 2$  and  $b = 4$ .



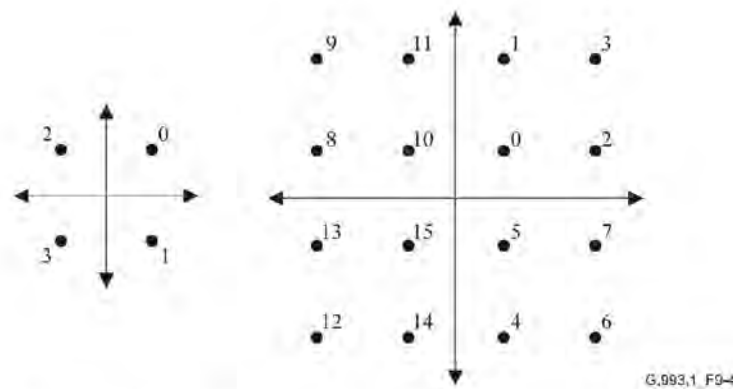


Figure 9-4/G.993.1 – Constellation labels for  $b = 2$  and  $b = 4$

The 4-bit constellation shall be obtained from the 2-bit constellation by replacing each label  $n$  by the  $2 \times 2$  block of labels:

$$\begin{array}{cc} 4n+1 & 4n+3 \\ 4n & 4n+2 \end{array}$$

The same procedure shall be used to construct the larger even-bit constellations recursively. The constellations obtained for even values of  $b$  are square in shape.

#### 9.2.5.2 Odd values of $b$ , $b = 1$ or $b = 3$

Figure 9-5 shows the constellations for the cases  $b = 1$  and  $b = 3$ .

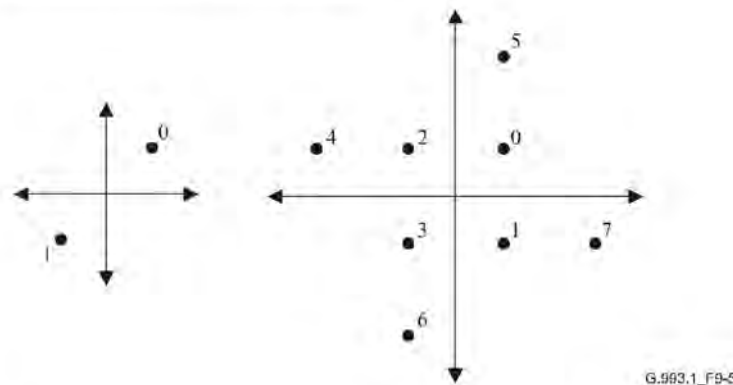


Figure 9-5/G.993.1 – Constellation labels for  $b = 1$  and  $b = 3$

#### 9.2.5.3 Odd values of $b$ , $b > 3$

If  $b$  is odd and greater than 3, the 2 MSBs of  $X$  and the 2 MSBs of  $Y$  shall be determined by the 5 MSBs of the  $b$  bits. Let  $c = (b+1)/2$ , then  $X$  and  $Y$  shall have the two's-complement binary representations  $(X_c, X_{c-1}, v_{b-4}, v_{b-6}, \dots, v_3, v_1, 1)$  and  $(Y_c, Y_{c-1}, v_{b-5}, v_{b-7}, v_{b-9}, \dots, v_2, v_0, 1)$ , where  $X_c$  and  $Y_c$  are the sign bits of  $X$  and  $Y$ , respectively. These values require appropriate scaling such that, at the output of the constellation mapper, all constellations regardless of size represent the same RMS energy as a subcarrier transmitted at a level equal to the PSD template. The relationship between  $X_c, X_{c-1}, Y_c, Y_{c-1}$ , and  $v_{b-1}, v_{b-2}, \dots, v_{b-5}$  shall be as shown in Table 9-2.

**Table 9-2/G.993.1 – Determining the top two bits of  $X$  and  $Y$** 

$v_{h-1}, v_{h-2}, \dots, v_{h-5}$	$X_c, X_{c-1}$	$Y_c, Y_{c-1}$
0 0 0 0 0	0 0	0 0
0 0 0 0 1	0 0	0 0
0 0 0 1 0	0 0	0 0
0 0 0 1 1	0 0	0 0
0 0 1 0 0	0 0	1 1
0 0 1 0 1	0 0	1 1
0 0 1 1 0	0 0	1 1
0 0 1 1 1	0 0	1 1
0 1 0 0 0	1 1	0 0
0 1 0 0 1	1 1	0 0
0 1 0 1 0	1 1	0 0
0 1 0 1 1	1 1	0 0
0 1 1 0 0	1 1	1 1
0 1 1 0 1	1 1	1 1
0 1 1 1 0	1 1	1 1
0 1 1 1 1	1 1	1 1
1 0 0 0 0	0 1	0 0
1 0 0 0 1	0 1	0 0
1 0 0 1 0	1 0	0 0
1 0 0 1 1	1 0	0 0
1 0 1 0 0	0 0	0 1
1 0 1 0 1	0 0	1 0
1 0 1 1 0	0 0	0 1
1 0 1 1 1	0 0	1 0
1 1 0 0 0	1 1	0 1
1 1 0 0 1	1 1	1 0
1 1 0 1 0	1 1	0 1
1 1 0 1 1	1 1	1 0
1 1 1 0 0	0 1	1 1
1 1 1 0 1	0 1	1 1
1 1 1 1 0	1 0	1 1
1 1 1 1 1	1 0	1 1

Figure 9-6 shows the constellation for the case  $b = 5$ .

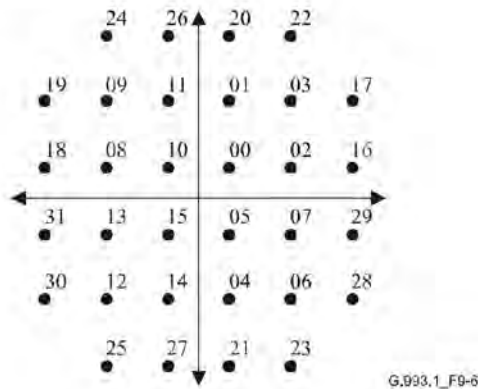


Figure 9-6/G.993.1 – Constellation labels for  $b = 5$

The 7-bit constellation shall be obtained from the 5-bit constellation by replacing each label  $n$  by the  $2 \times 2$  block of labels:

$$\begin{array}{cc} 4n + 1 & 4n + 3 \\ 4n & 4n + 2 \end{array}$$

The same procedure shall then be used to construct the larger odd-bit constellations recursively.

#### 9.2.6 Gain scaling

A gain adjuster  $g_i$  shall be used to achieve a frequency-variable transmit power spectral density (PSD). It shall consist of a fine gain adjustment with a range from approximately 0.75 to 1.33 (that is,  $\pm 2.5$  dB), which may be used to equalize the expected error rates for all the sub-channels. Each point  $(X_i, Y_i)$ , or complex number  $Z_i = X_i + jY_i$ , output from the encoder is multiplied by  $g_i$ :  $Z'_i = g_i Z_i$ .

#### 9.2.7 Tone ordering

Because the DMT symbol has a high peak to average power ratio (PAR), peak values in the signal may be clipped by the D/A-converter. To a first approximation, this leads to an additive noise that is comparable with impulse noise (with an amplitude equal to the clipped portion, but with opposite sign). This noise will be almost white over all the tones. It is likely that the tones with the densest constellations (i.e., the tones with the largest SNR) will be more affected when this noise is present. Thus, the occurrence of an error is more likely on these tones due to the smaller distance between the constellation points.

If the dual latency option is supported, bits in the slow buffer shall be assigned to tones with the highest SNRs. With this scheme, occasional errors on these tones due to clipping can be corrected by the combination of interleaving and RS coding. The bits on tones with smaller constellations are less likely to be in error due to clipping noise and shall therefore support bits from the fast buffer.

The "tone-ordered" encoding shall first assign all the bits from the fast buffer to the tones with the smallest number of bits assigned to them, and then assign all the bits from the interleaved buffer to the remaining tones. All tones shall be encoded with the number of bits assigned to them. Therefore, a single tone may support a mixture of bits from the fast and slow buffers.



The ordered bit table  $b'_i$  shall be based on the original bit table  $b_i$  as follows:

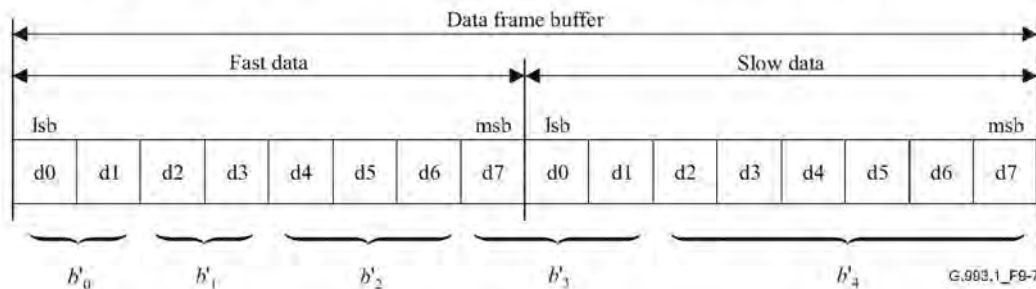
For  $k = 0$  to  $B_{max}$

- From the bit table, find the set of all  $i$  with the number of bits per tone  $b_i = k$ ;
- Assign  $b_i$  to the ordered bit allocation table in ascending order of  $i$ .

A complementary de-ordering procedure shall be performed by the receiver at the other end of the line. It is not necessary to transmit the results of the ordering procedure to the receiver because all the information required to perform the de-ordering already exists at the receiver.

If only one single-latency channel is supported, bits shall be assigned to tones starting from the lowest available frequency based on the original bit table  $b_i$ .

Figure 9-7 illustrates how the bits shall be extracted from the fast and interleaved data buffer when tone-ordering is applied. In this example, both fast and interleaved buffer are one byte long. Following the above rule, the first bits shall be taken from the fast buffer, starting from the LSB and shall be placed on the tones with the lowest number of bits assigned to it. The fourth tone to be loaded (carrying  $b'_3$ ' bits) shall take bits from both the fast and the slow buffer.



**Figure 9-7/G.993.1 – Bit extraction after tone ordering**

## 10 Management

### 10.1 OAM functional model

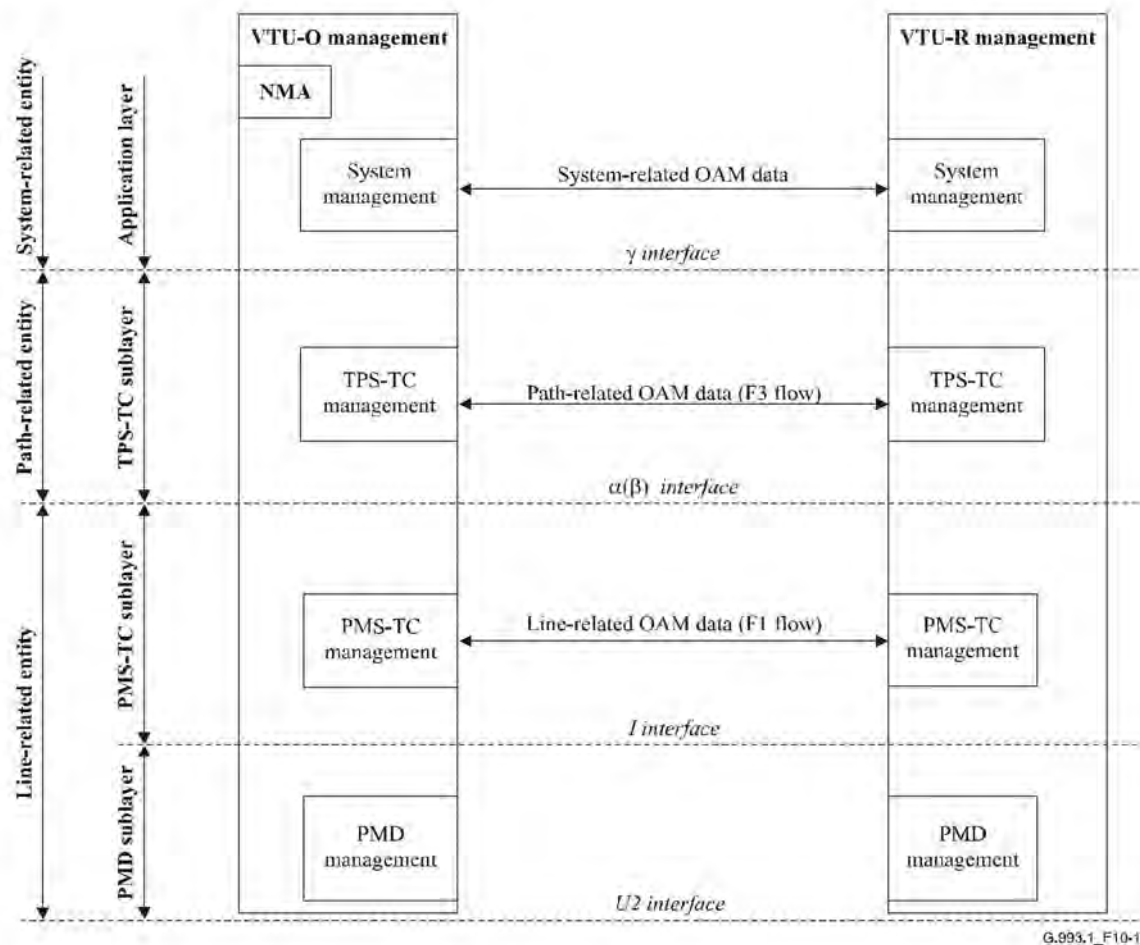
The OAM functional model of a VDSL link, as shown in Figure 10-1, contains OAM entities intended to manage the following transmission entities:

- *VDSL Line entity*: the physical transport vehicle provided by PMD and PMS-TC transmission sublayers.
- *VDSL Path entity*: the applicable transport protocol path, provided by TPS-TC sublayer. A path could be either for a single application (single latency, single transport protocol) or multiple, including optionally different transport protocols over single and dual latency.
- *VDSL System entity*: the user-application path, provided by the layers higher than TC. This path also provides the high level OAM functionality between the VTU-O and the VTU-R.

The structure of OAM entities at both the VTU-O and VTU-R is identical. The data exchange between the management processes of the peer OAM entities at the VTU-O and VTU-R is established over three OAM-dedicated communication channels.

Management process also assumes an exchange of management information inside the VTU between the OAM entities and the Network Management Agent (NMA). Such exchange is accomplished:

- via  $\gamma$  interface: between the NMA and the TPS-TC;
- via  $\alpha(\beta)$  interface: between the NMA and PMS-TC/PMD.



**Figure 10-1/G.993.1 – OAM functional model**

The OAM flows across both interfaces are bidirectional. They convey, respectively, path-related and line-related primitives and parameters, configuration set-ups, and maintenance commands and acknowledgments of the certain levels.

NOTE – The OAM flow rate should meet requirements for performance calculation and enable the required system management response time.

## 10.2 OAM communication channels

The following three OAM dedicated communication channels shall be arranged to provide OAM data transfer between the VTU-O and VTU-R:

- Indicator Bits (IB) channel;
- embedded operations channel (eoc);
- VDSL Overhead Control (VOC) Channel.

The three OAM channels shall provide transport of the following OAM data:

- primitives (anomalies, defects, failures) from all the transmission entities;
- parameters (performance and testing);
- configuration set-up;
- maintenance signals.



The interface between a certain OAM channel and the corresponding OAM entity is functional. It is defined by a specific communication protocol and a list of transferred information, including a part for proprietary use. Each OAM channel has specific characteristics and is intended to bear a specific type of OAM data. Partitioning of the OAM data between different OAM channels is described in 10.2.4.

#### 10.2.1 Indicator bits

The IB transport is supported by the PMS-TC sublayer. The IB are used to arrange communication channels between the peer OAM entities intended to transfer the far-end time-sensitive primitives, which require immediate action at the opposite side. The IB channel shall work in unidirectional mode, i.e., independently in both the upstream and downstream directions. The main data to be sent over IB is information on defects/failures, where timing is critical. The IB may also transfer other line-related and path-related primitives. The list of minimum required IB is specified in 10.5.4.

#### 10.2.2 VDSL embedded operations channel (eoc)

The eoc is supported at the system (application) layer. The eoc is a clear channel to exchange the VDSL system management data and to control traffic between the VTU-O and VTU-R. The exchanged data includes system-related primitives, performance parameters, test parameters, configuration and maintenance.

The eoc, except some special cases, works in bidirectional mode using an echoing protocol. Both transmission directions are required to provide communication for the eoc. The clear eoc channel interface is equal for both the VTU-O and VTU-R. The eoc is specified in 10.3.

#### 10.2.3 VDSL overhead control (VOC) channel

The VOC channel is supported by the TPS-TC sublayer and is intended mainly to transfer VDSL link activation and configuration message between the VTU-O and VTU-R. The VOC channel may also transfer line-related and path-related primitives.

The VOC channel works in a bidirectional mode using an echoing protocol and, hence, both transmission directions are required to provide communication for the VOC. The VOC is specified in 10.6.

#### 10.2.4 Partitioning of OAM data

The OAM data at both the VTU-O and VTU-R, after being collected from different entities, is stored in the corresponding part of MIB and then could be transferred to the far-end over the corresponding OAM channel. Partitioning of the OAM data between different OAM communication channels is summarized in Table 10-1.

**Table 10-1/G.993.1 – OAM data partitioning**

OAM data	Transferred to the far-end by:	Notes
<i>Primitives</i>		
Line-related, time-sensitive	IB	PMD and PMS-TC defects
Path-related, time-sensitive		TPS defects/failures (Note 1), separately for each TPS-TC
Line-related, time-insensitive	IB or VOC	PMD and PMS-TC anomalies
Path-related, time-insensitive	IB or eoc (Note 1)	TPS anomalies, separately for each TPS-TC
System-related primitives	IB or eoc (Note 2)	

**Table 10-1/G.993.1 – OAM data partitioning**

OAM data	Transferred to the far-end by:	Notes
<i>Parameters</i>		
Line-related, performance	None	Calculated from retrieved line-related and path-related primitives
Path-related, performance		
Path-related, testing	eoc	For some TPS-TC
Line-related, testing		ATT, SNR margin and other local measurements
Self-test		For some VTU blocks or completely
VTU identification		Vendor ID, revision number, serial number
Service modules parameters		Proprietary (Service modules performance, test or other parameters)
<i>Configuration</i>		
Line-related parameters	VOC or eoc	Frame structure, interleaving depth, etc.
Path-related parameters	eoc	With respect to the applied TPS-TC
System-related parameters	eoc	Proprietary, respective to the applied service modules
<i>Maintenance</i>		
VTU state control	eoc	Hold the state, return to normal state
Self-test activation		A complete VTU self-test and self sub-tests on specific VTU blocks
Loopback activation		At TPS-TC and application layers
Performance monitoring supervision		Request for FEC corruption test, notify FEC corruption test
NOTE 1 – The IB are necessary to monitor the primitives which destroy the path (for instance, ATM cell delineation loss). The anomalies in a certain active path are monitored by the corresponding TPS-TC management function and delivered to the other side by the standard means of the applicable transport protocol (TP), IB or VOC.		
NOTE 2 – eoc is preferable for system-related primitives.		

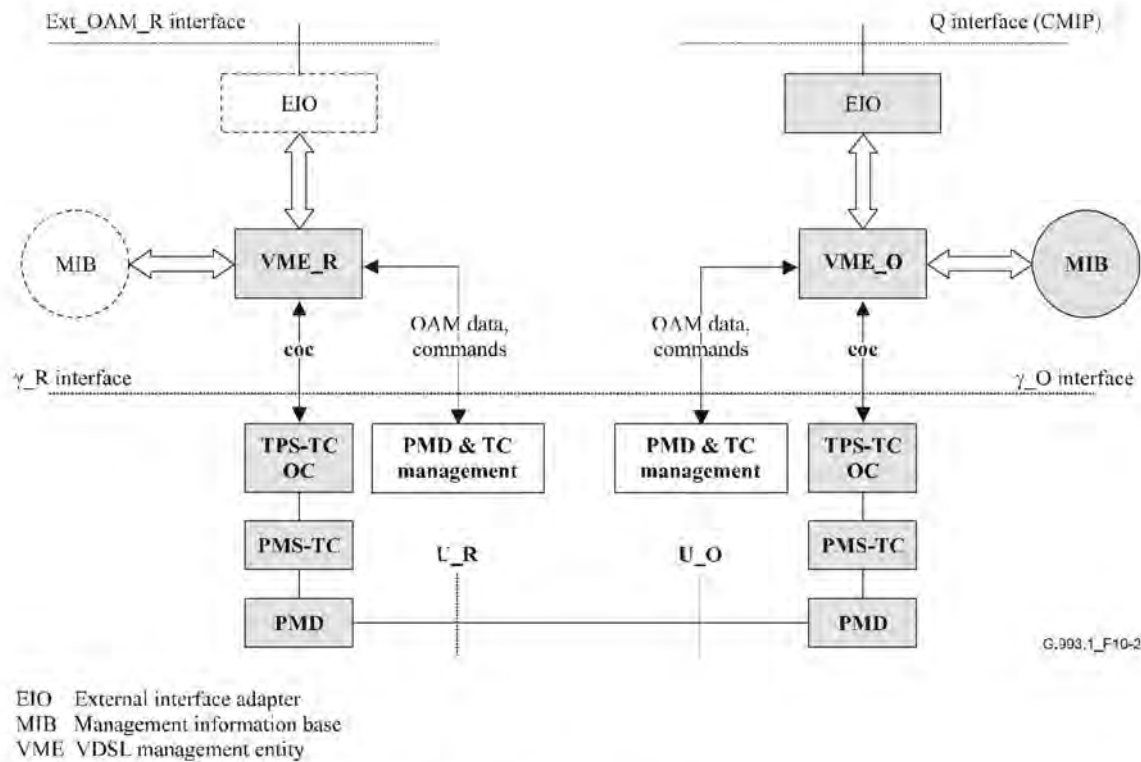
### 10.3 Embedded operations channel (eoc) functions and description

Embedded Operations Channel (eoc) is intended to exchange the system management data and control traffic between the VTU-O and VTU-R. The exchanged data includes system-related primitives, performance parameters, test parameters, configuration and maintenance commands. The specified eoc can provide both "internal" management functions to support the VDSL transceiver and to be used as a clear management channel between the VTU-O and VTU-R.

#### 10.3.1 eoc functional model

The eoc functional model is presented in Figure 10-2. The eoc traffic between the VTU-O and VTU-R may include either internal eoc traffic (originated in the VTU-O) or external eoc traffic, delivered through the external Q interface. The VTU-O Management Entity (VME\_O) multiplexes the internal and the external traffics into an eoc information stream. The latest is formatted and presented at the  $\gamma_O$  interface to be sent transparently over the VDSL link to the VTU-R Management Entity (VME\_R).





**Figure 10-2/G.993.1 – eoc functional model**

The Management Information Base (MIB) contains all the management information related to the VDSL link. It may be implemented either as a part of the VTU-O or as a common part to be shared between several VTU-Os. In the first case, the Network Management Agent (located outside of the VTU-O) accesses the MIB via the Q interface and should be supported by the VME\_O. If the MIB belongs to the common part of the ONU, VME\_O accesses MIB (if necessary) via the Q interface. At the VTU\_R, the MIB and external interface support are optional.

#### 10.3.1.1 VME functionality

VME (both the VME\_O and VME\_R) shall provide at least the following management functions over the VDSL link:

- performance management;
- configuration management;
- fault management.
- support of the external interface (Q-interface) and MIB interface (only mandatory for the VME\_O).

NOTE 1 – This part of VME functionality is beyond the scope of this Recommendation.

The VME provides management functions at the remote end via eoc including:

- support of VDSL link (maintenance and fault management);
- performance monitoring (in addition or instead available indicator bits/VOC), including precision measurements for QoS confirmation;
- configuration management of TPS-TC and, optionally, of PMS-TC;
- user interface related functions.

NOTE 2 – This part of VME functionality is beyond the scope of this Recommendation.

The VME shall also provide the following eoc-related functionality:

- support of the eoc protocol at the  $\gamma$  interface;
- multiplexing/de-multiplexing of the internal and external eoc traffic.

### 10.3.2 eoc protocol and messages

The same eoc protocol format shall be used on the  $\gamma$  interface at both sides of the link. The eoc protocol format shall implement HDLC protocol as it is defined in ITU-T Rec. G.997.1. The use of the information payload of the HDLC frame is defined in the following clauses.

The VME shall multiplex internal eoc and external messages received via the Q interface, and combine them into a standard HDLC frame. To be transported over the VDSL links, external messages shall get the HDLC address field value of "0xFF" as it is defined in ITU-T Rec. G.997.1. The internal eoc messages may have an HDLC address field with a value of "0x11".

#### 10.3.2.1 External message format

The information payload of the HDLC frame carrying an external message shall not exceed 510 octets. The encapsulation method and the contents of external messages are beyond the scope of this Recommendation.

#### 10.3.2.2 Internal message format

The information payload of the HDLC frame carrying an internal message (further denoted as "eoc message") shall contain at least 2 octets sent from the VME\_O to the VME\_R and vice versa.

#### 10.3.2.3 eoc organization and message types

The eoc allows the VTU-O (acting as a master) to invoke certain management functions at the VTU-R by sending eoc command messages. The VTU-R (acting as a slave) shall acknowledge a command message it has received correctly by sending a response eoc message (echo) and performing the requested function. The echo shall be a copy of the corresponding command message. In exception to this, autonomous messages may be sent from the VTU-R independently (as soon as the appropriate data is available) but not in response to a VTU-O message.

There are three types of eoc messages specified:

- *bidirectional messages (d/u)*: these are originated by the VTU-O, and echoed by the VTU-R to indicate a correct reception of each message;
- *downstream messages (d)*: these are originated by the VTU-O and not echoed, but always acknowledged by a different message from the VTU-R;
- *upstream messages (u)*: these are originated by the VTU-R and may be in response to a downstream message or autonomous.

NOTE – Acting as a master, the VTU-O usually determines the rate of the eoc communication, as the VTU-R responds by only one echo message following receipt of each eoc command message.

#### 10.3.2.3.1 eoc message structure

The 16 bits of an eoc message are partitioned among six fields, which are summarized in Table 10-2 and defined in the following subclauses. The first 13 MSB of the transmitted 2-octet eoc data shall be used for the eoc message starting from bit #1. The last three LSB shall be reserved.



**Table 10-2/G.993.1 – eoc message fields**

Field #	Bit #	Description	Notes
1	1-2	ADDRESS field	Can address up to 4 locations
2	3	DATA (0) or OPCODE (1) field	Data used for both read and write
3	4	PARITY field Odd (1) or Even (0)	Byte order indication for multi-byte transmission
4	5	MESSAGE/RESPONSE field Message/Response (1) or Autonomous message (0)	Currently, autonomous messages are defined for the VTU-R only.
5	6-13	INFORMATION field	One out of 58 OPCODEs or 8 bits of data
6	14-16	Reserved	For future use

**10.3.2.3.1.1 Address field (# 1)**

The two bits of the address field can address up to four locations. Only two locations are presently defined:

- 11: VTU-O address;
- 00: VTU-R address;
- 01, 10: Reserved for future applications; presently invalid.

The VTU-O shall address messages to the VTU-R by setting the ADDRESS field equal to the VTU-R address (00). When responding to a message received from the VTU-O, the VTU-R shall keep the ADDRESS field equal to the VTU-R address (00). The VTU-R shall set the ADDRESS field equal to the VTU-O address (11) only when sending an autonomous message to the VTU-O.

**10.3.2.3.1.2 Data or OPCODE field (# 2)**

A "0" in this field indicates that the information field of the eoc message contains a data byte; a "1" indicates that it contains an OPCODE.

**10.3.2.3.1.3 Parity field (# 3)**

This bit helps to speed up the multi-byte reads and writes of data by eliminating the intermediate messages to indicate to the far end that the previous byte was successfully received.

For the first byte of the sent read/write data, this bit shall be set to "1" to indicate an "odd" byte. For the next byte, it shall be set to "0" to indicate an "even" byte and so on, alternately.

The PARITY field shall always be set to "1" if the information field carries an OPCODE different from the "Next Byte" OPCODE. If a "Next Byte" OPCODE is applied, the PARITY field is toggled for multi-byte data transfer.

**10.3.2.3.1.4 Message/response field (# 4)**

A "1" in this field designates that the current eoc message is an eoc command message or an eoc response message (echo); a "0" designates that it is an autonomous message.

NOTE – For the VTU-O, this field shall always be set to "1". For the VTU-R, this field shall also be set to "1" except for the autonomous messages.

**10.3.2.3.1.5 Information field (# 5)**

Up to 58 different 8-bit OPCODEs or an 8-bit data may be encoded in the information field.

The OPCODE set is restricted to codes that provide a minimum Hamming distance of 2 between all OPCODEs, and a minimum distance of 3 between certain critical codes and all other codes.

**10.3.2.3.2 eoc message set**

All the eoc messages and their OPCODEs are summarized in Table 10-3.

**Table 10-3/G.993.1 – The eoc message set list**

OPCODE (HEX)	OPCODE meaning	Direction	Abbreviation and notes
01	Hold state	d/u	HOLD
F0	Return-To-Normal	d/u	RTN
02	Perform "self test"	d/u	SLFTST
04	Unable-to-comply	u	UTC
07	Request for corrupted CRC/FEC	d/u	REQCOR (latching)
08	Request end of corrupted CRC/FEC	d/u	REQEND
0B	Notify corrupted CRC/FEC	d/u	NOTCOR (latching)
0D	Notify end of corrupted CRC/FEC	d/u	NOTEND
0E	End of data	d/u	EOD
10	Next byte	d	NEXT
13	Request test parameters update	d/u	REQTPU
14	Error	d/u	ERR
20, 23, 25, 26, 29, 2A, 2C, 2F, 31, 32, 34, 37, 38, 3B, 3D, 3E	Write data register with numbers from 0x0 to 0xF, respectively, as specified in Table 10-4	d/u	WRITE
40, 43, 45, 46, 49, 4A, 4C, 4F, 51, 52, 54, 57, 58, 5B, 5D, 5E	Read data register with numbers from 0x0 to 0xF, respectively, as specified in Table 10-4	d/u	READ
19, 1A, 1C, 1F	Vendor proprietary protocols	d/u	Four OPCODEs are reserved for vendor proprietary use.
15, 16, 80, 83, 85, 86, 89, 8A, 8C, 8F	Undefined codes		These codes are reserved for future use and shall not be used for any purpose.
NOTE – The given OPCODE values guarantee a minimum Hamming distance of 2 between all OPCODEs (by requiring odd parity for all but two critical codes), and Hamming distance of 3 between the "Return to Normal" (or "idle") code and all other codes.			

The VTU-O shall send command messages to perform certain functions at the VTU-R. Some of these functions require the VTU-R to activate changes in the circuitry (e.g., to send corrupted CRC/FEC bits). Other functions are to read from and to write into the MIB data registers at the VTU-R. These functions are used by the VTU-O to read the VTU-R status or performance parameters, or for limited maintenance extensions to the service modules.

Some of eoc commands are "latching", meaning that a subsequent eoc command shall be required to release the VTU-R from that state. Thus, multiple VDSL eoc-initiated functions can be in effect simultaneously. To maintain the latched state, the command "Hold State" shall be sent.

A command, "Return-To-Normal" is used to unlatch all latched states. This command is also used to bring the VDSL system to the Idle state, when no eoc command is active in the VTU-R.



### 10.3.2.3.3 Bidirectional eoc messages

Each bidirectional message sent by the VTU-O shall be echoed by the VTU-R if received correctly. The following messages are specified as bidirectional (with their abbreviated names and hex OPCODEs in parentheses):

- *Hold State (HOLD, 01)*: This message tells the VME-R to maintain the VTU-R eoc processor and any active VDSL eoc-controlled operations (such as latching commands) in their present state;
- *Return to Normal (Idle Code) (RTN, F0)*: This message releases all outstanding eoc-controlled operations (latched conditions) at the VTU-R and returns the VDSL eoc processor to its initial state;
- *Request Corrupt CRC/FEC (REQCOR, 07)*: This message requests the VTU-R to send corrupt CRC/FECs to the VTU-O until cancelled by the "Request End of Corrupt FEC" or "Return-To-Normal" message. In order to allow multiple VDSL eoc-initiated actions to be in effect simultaneously, the "Request corrupt FEC" command shall be latching;
- *Request End of Corrupt CRC/FEC (REQEND, 08)*: This message requests the VTU-R to stop sending corrupt CRC/FECs toward the VTU-O;
- *Notify Corrupted CRC/FEC (NOTCOR, 0B)*: This message notifies the VTU-R that intentionally corrupted CRC/FECs will be sent from the VTU-O until cancellation is indicated by "Notify End of Corrupted CRC/FEC" and "Return-To-Normal";
- *Notify End of Corrupted CRC/FEC (NOTEND, 0D)*: This message notifies the VTU-R that the VTU-O has stopped sending corrupted CRC/FECs;
- *Perform Self-Test (SLFTST, 02)*: This message requests the VTU-R to perform a self-test. The result of the self-test shall be stored in a register at the VTU-R. After the VTU-R self-test, the VTU-O reads the test results from the VTU-R register;
- *Receive/Write Data (Register #) (WRITE, see 10.3.2.5.3.2)*: This message directs the VTU-R to enter the Data Write Protocol state, receive data, and write it in the register specified by the OPCODE;
- *Read/Send Data (Register #) (READ, see 10.3.2.5.3.1)*: This message directs the VTU-R to enter the Data Read Protocol state, read data from the register specified by the OPCODE, and transmit it to the VTU-O;
- *End of Data (EOD, 0E)*: This message is sent by the VTU-O after it has sent all bytes of data to the VTU-R. The message is sent by the VTU-R in either of the following cases:
  - in response to a "Next Byte" message from the VTU-O that is received after all bytes have been read from the currently addressed VTU-R register;
  - in response to a message from the VTU-O that contains a data byte after all bytes have been written to the currently addressed VTU-R register;
- *Vendor Proprietary OPCODEs (VPC, 19, 1A, 1C, 1F)*: Four OPCODEs have been reserved for vendor-proprietary use. The VTU-O shall read the Vendor ID code register of the VTU-R to ensure compatibility between the VTUs before using proprietary OPCODEs;
- *Request Test Parameters Update (REQTPU, 13)*: This message requests the VTU-R to update the test parameters set as defined in 10.4.2. Test parameters supported by the VTU-R shall be updated within 10 s after the request is received. Updated test parameters may be read by the VTU-O thereafter;
- *Error (ERR, 14)*: This message requests the opposite side to repeat the last message. The message is sent as a response on a non-correctable error detected in the received HDLC frame.

#### 10.3.2.3.4 Downstream messages

One message is specified that may be sent only by the VTU-O:

- *next byte (NEXT, 10)*: This message is sent repeatedly by the VTU-O (toggling bit four for multi-byte data until all data has been sent) while it is in Data Read protocol state. As a reply to this message, either the requested byte of the VTU-R data is sent, with bit four toggled for multi-byte data or the *End-of-Data* message is sent.

#### 10.3.2.3.5 Upstream messages

The messages that may be sent only by the VTU-R are:

- *Unable-to-Comply (UTC) (UTC, 04), acknowledgment*: The VTU-R shall send this message when it receives a command or *eoc* message that it cannot perform for any of the following reasons:
  - it does not recognize the command;
  - it cannot implement the command;
  - the command is unexpected for the current state of the *eoc* protocol;
- *autonomous messages*. All autonomous messages have bit 5 set to "0" and bit 3 set to "1" to indicate that the message contains an OPCODE. The information field shall contain the OPCODE of the corresponding message (see Table 10-3).

#### 10.3.2.4 VTU-R data registers

The VTU-R data registers shall be defined as:

- *VTU-R Vendor ID code (4 bytes)*: The format of the VTU-R Vendor ID code is undefined;
- *VTU-R Revision number (2 bytes)*: The format of the VTU-R Revision Number is vendor-discretionary;
- *VTU-R Serial number (32 bytes)*: The format of the VTU-R serial number is vendor-discretionary;
- *Self-Test Results*: The most significant byte of the Self-Test Results shall be 0x00 if the self-test passed, and 0x01 if it failed (the meaning of "failure" is vendor-discretionary); other values are reserved for future use. The length and syntax of the remainder shall be vendor-discretionary;
- *Performance (16 bytes)*: Contains the downstream attainable line rate as well as the VTU-R corrected and uncorrected error counts. Used to retrieve data for computation of various error performance parameters. Bytes 0x00-0x03 indicate the attainable downstream data rate in 1-kbit/s steps. Bytes 0x04-0x05 indicate the number of corrected error octets in the slow channel. Bytes 0x06-0x07 indicate the number of corrected error octets in the fast channel. Bytes 0x08-0x09 indicate the number of uncorrected error octets in the slow channel. Bytes 0x0A-0x0B indicate the number of uncorrected error octets in the fast channel. Bytes 0x0C-0x0F are reserved and shall be set to 0xFF.
- *Loop attenuation (Minimum 1 byte)*: The loop attenuation format shall be as defined in 10.5.6;
- *SNR Margin (Minimum 1 byte)*: The SNR margin format shall be as defined in 10.5.6;
- *VTU-R configuration (64 bytes)*: The VTU-R configuration registers contain the relevant data for PMD, PMS-TC, and TPS-TC configuration. This data is established during the link initialization via the VOC.

Table 10-4 summarizes the VTU-R data registers and their applications including the format and detailed contents of VTU-R registers.



**Table 10-4/G.993.1 – VTU-R data registers**

<b>REG # (HEX)</b>	<b>Use</b>	<b>Length</b>	<b>Description</b>
0	Read	4 bytes	VTU-R vendor ID
1	Read	2 bytes	VTU-R revision number
2	Read	32 bytes	VTU-R serial number
3	Read	Vendor-discretionary	Self-test results
4	Read	16 bytes	Performance
5	Read/Write	Vendor-discretionary	Vendor-discretionary
6	Read/Write	Minimum of one byte; additional bytes are Vendor-discretionary	Loop attenuation
7	Read	Minimum of one byte; additional bytes are vendor-discretionary	SNR margin
8	Read	64 bytes	VTU-R configuration
9-F	Read	Reserved	For future use

All VTU-R registers shall be read MSB first. The VTU-R shall respond UTC if requested to write into the Read register.

### **10.3.2.5 eoc protocol states**

#### **10.3.2.5.1 Message/echo-response protocol state (idle state)**

To initiate an action at the VTU-R, the VTU-O shall begin sending eoc messages with the Data/OPCODE set to "1" and with the appropriate message OPCODE in the information field. The VTU-R shall initiate the action only when an error-free and properly addressed eoc messages has been received. The VTU-R shall respond to all the received messages by an echo of the received message. If either the VTU-R or VTU-O detects a non-correctable error in the received HDLC frame, it shall send the *Error* message. The combination of the VTU-O sending a message and the VTU-R echoing the message back comprises the message/echo-response protocol state.

If the eoc message is one of the latching commands, the VTU-R shall maintain the commanded condition until the VTU-O issues the appropriate command to end the specific latched condition or until the VTU-O issues the "*Return-to-Normal*" command.

NOTE – The time it takes to complete an eoc message transmission under both error and error-free conditions depends on the vendor's implementation.

#### **10.3.2.5.2 Message/unable-to-comply response protocol state (UTC state)**

When the VTU-R does not support the function requested by a message that it has properly received, it shall respond with the UTC message with its own address and switch to the UTC state. The reception by the VTU-O of a properly addressed UTC message constitutes notification to the VTU-O that the VTU-R does not support the requested function.

#### **10.3.2.5.3 Message/data-response protocol state**

The VTU-O may either write data into, or read data from, the VTU-R MIB.



#### 10.3.2.5.3.1 Data read protocol

To read data from the VTU-R, the VTU-O shall send a *Send Data* OPCODE message to the VTU-R which specifies the register to be read. After receiving the acknowledgment, the VTU-O shall request the first byte to be sent from the VTU-R by sending *Next Byte* message with bit 4 set to "1", indicating a request for an *odd* byte. The VTU-R shall respond to this *Next Byte* message by sending the first byte of the requested data in the information field of an eoc message with bit 4 set to "1" to indicate *odd byte* and with bit 3 set to "0" to indicate the eoc data message. If there are more data to be read, the VTU-O shall request the second byte of data by sending *Next Byte* messages with bit 4 set to "0" ("even byte"). The VTU-R responds to the message by sending eoc message containing the second byte of the register with bit 4 set to *even byte*. The process continues for the third and all subsequent bytes with the value of bit 4 toggling from *odd byte* to *even byte* or vice versa, on each succeeding byte. Each time bit 4 is toggled, the VTU-R responds by sending the next data octet. The process ends only when all the requested data in the register has been read.

To continue reading data, once the VTU-R is in the *Data Read odd or even state*, the only message that the VTU-O is allowed to send is *Next Byte* with bit 4 toggling. To end the data-read mode abnormally, the VTU-O sends either *Hold State* or *Return to Normal*, depending on whether any latched states are to be retained. If the VTU-R receives any other message while it is in *Data Read odd or even state*, it shall go into the *UTC state*.

If, after all bytes have been read from the VTU-R register, the VTU-O continues to send the *Next Byte* message with bit 4 toggled, then the VTU-R shall send an *End-of-Data* message.

For the VTU-O, the *data-read mode* ends either after the VTU-O receives the last requested data byte, or after the VTU-O receives the *End-of-Data* message. The VTU-O shall then switch both itself and the VTU-R into the *Idle State* (by sending a *Hold State* or a *Return-to-Normal* message), and the VTU-R shall release the register and leave the *Data Read state* after receiving either *Hold State* or *Return-to-Normal* message.

#### 10.3.2.5.3.2 Data write protocol

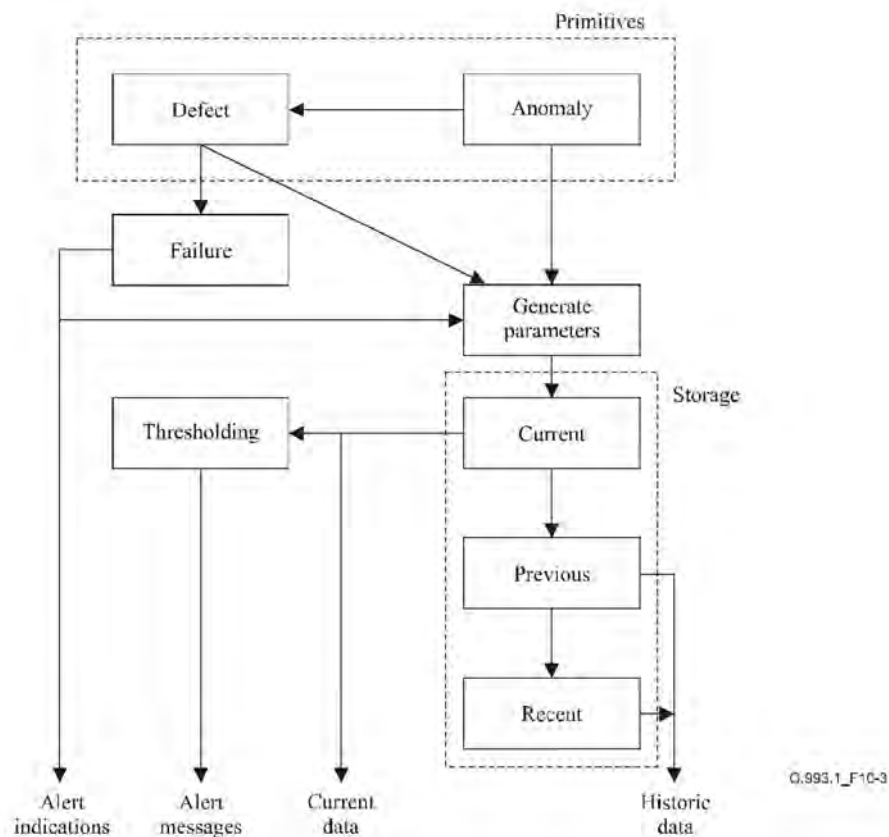
To write data into the VTU-R MIB, the VTU-O shall send a *Write Data* OPCODE message to the VTU-R that specifies the register to be written. When the VTU-R acknowledges (echoing), the VTU-O sends the first byte of data. The VTU-R shall acknowledge the receipt of the byte with an echo of the message. After the VTU-O receives the echo response, it shall send the next byte of data. Each time the VTU-O receives echo response, it shall switch to sending the next byte of data. It shall also toggle the "odd/even" bit accordingly. (*Next Byte* messages are not used in the *Data-Write mode*). The VTU-O shall end the write mode with the *End-of-Data* message indicating to the VTU-R to release the register and return to the *Idle State*.

To continue writing data once the VTU-R is in the *Data Write odd or even state*, the only message that the VTU-O is allowed to send is the *Data Byte* message with bit 3 set to "0" and with bit 4 toggling. To end the *Data Write state* abnormally, the VTU-O may switch to the *End-of-Data* message. If the VTU-R receives any other message while it is in *Data Write state*, it shall go into the *UTC state*.

If, after all bytes have been written to the VTU-R register, the VTU-O continues to send the data, then the VTU-R shall send an *End-of-Data* message.

### 10.4 Fault and performance monitoring

The general process of fault and performance monitoring is based on performance primitives, as shown in Figure 10-3, and expressed by applicable performance parameters.



**Figure 10-3/G.993.1 – Performance monitoring process**

The following definitions are applicable:

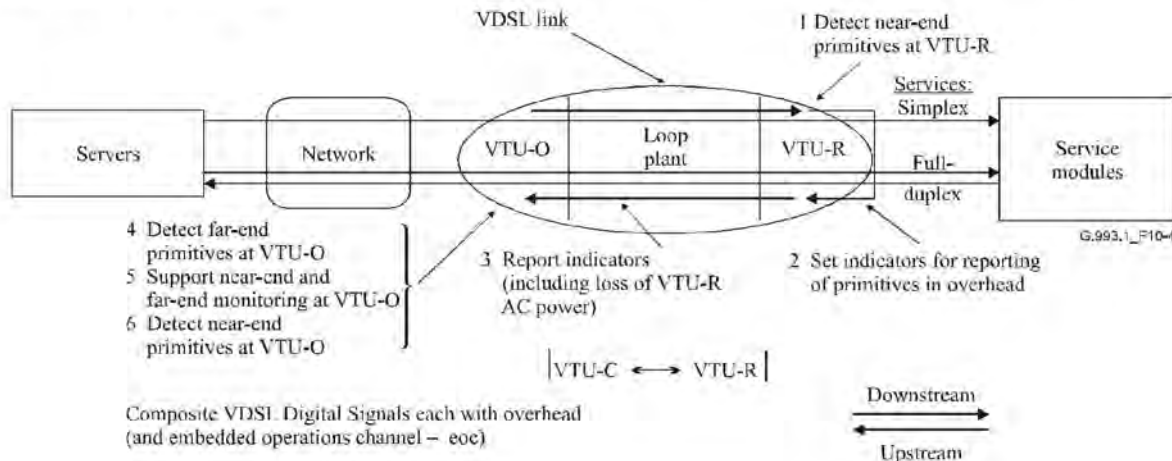
- **Primitives:** Primitives are basic measures of performance. Performance primitives are categorized as anomalies and defects. Primitives may also be basic measures of other quantities (e.g., ac or battery power), usually obtained from equipment indicators.
- Near-end primitives are usually detected by monitoring the local signal protocols and frame formats.
- Far-end primitives are detected by reading fields in the overhead that are defined to report the nature and number of basic error events or other performance-related occurrences detected at the far-end.
- **Anomalies:** An anomaly is a discrepancy between the actual and desired characteristics of an item. The desired characteristic may be expressed in the form of a specification. An anomaly may or may not affect the ability of an item to perform a required function.
- **Defects:** A defect is a limited interruption in the ability to perform a required function. It may or may not lead to maintenance action depending on the result of additional analysis. Successive anomalies causing a decrease in the ability of an item to perform a required function are considered as a defect.
- **Failures:** A failure is the termination of an item's ability to perform a required function. At a network element, both local and remote failures can be observed. Local failures include



near-end signal failures. Remote failures are those that occur and are recognized elsewhere, and are reported within the transmission signal.

- **Parameters:** These parameters are counts of the various impairment events detected during the accumulation period. Performance parameters are directly derived from the corresponding performance primitives.
- **Thresholding:** All performance parameters (e.g., errored seconds) have associated thresholds, which may be set, read, or changed by the Network Management System (NMS) that is doing performance monitoring. A threshold crossing for performance parameters may be autonomously reported to the NMS by the VTU-O.

Figure 10-4 describes graphically the near-end and far-end performance monitoring concepts applied to a VDSL link.



**Figure 10-4/G.993.1 – In-service surveillance of the VDSL link shown from the VTU-O's standpoint**

## 10.5 OAM parameters and primitives

### 10.5.1 Line-related primitives

Any of the detected line-related primitives is represented by a corresponding indicator at the OAM interface of  $\alpha(\beta)$  reference point. The indicator shall be coded "0" to indicate that no anomaly, defect or failure has been registered since the previous transmission period and shall be coded "1" to indicate that at least one anomaly, defect or failure has been registered since the previous transmission period.

All the near-end anomalies, defects and failures should be represented at both the VTU-O and VTU-R. The representation of far-end anomalies, defects and failures at the VTU-R is *optional*. The representation of far-end anomalies at the VTU-O is mandatory.

#### 10.5.1.1 Near-end anomalies

- *Forward Error Correction – Fast data (fec-f)* anomaly occurs when errored octets corrected by the FEC have been detected in the received block of fast data.
- *Forward Error Correction – Slow data (fec-s)* anomaly occurs when errored octets corrected by the FEC have been detected in the received block of slow data.
- *Block Error – Fast data (be-f)* anomaly occurs when non-corrected errors have been detected in the received block of fast data.

- *Block Error – Slow data (be-s)* anomaly occurs when non-corrected errors have been detected in the received block of slow data.

#### 10.5.1.2 Far-end anomalies

- *Far-end Forward Error Correction – Fast data (ffec-f)* anomaly occurs when a *fec-f* anomaly detected at the far end is reported. A *ffec-f* anomaly terminates when the received report on *fec-f* anomaly is set to "0".
- *Far-end Forward Error Correction – Slow data (ffec-s)* anomaly occurs when a *fec-s* anomaly detected at the far end is reported. A *ffec-s* anomaly terminates when the received report on *fec-s* anomaly is set to "0".
- *Far-end Block Error – Fast data (febe-f)* anomaly occurs when a *be-f* anomaly detected at the far end is reported. A *febe-f* anomaly terminates when the received report on *febe-f* indicator is set to "0".
- *Far-end Block Error – Slow data (febe-s)* anomaly occurs when a *be-s* anomaly detected at the far end is reported. A *febe-s* anomaly terminates when the received report on *febe-s* indicator is set to "0".

#### 10.5.1.3 Near-end defects

- *Loss-of-Signal (los)* A reference power is established by averaging the VDSL power over a 0.1 s period and over a subset of carriers after the start of steady state transmission and a threshold shall be set 6 dB below this. A *los* defect occurs when the level of the received VDSL power averaged over a 0.1-s period and over the same subset of carriers is lower than the threshold, and terminates when this level, measured in the same way, is at or above the threshold. The subset of carriers is implementation dependent.
- *Severely Errored Frame (sef)* defect is managed in accordance with the transmission frame delineation state diagram. A *sef* defect occurs with a transition out of synchronization (SYNC) state of the frame delineation state machine and terminates with a transition into the SYNC state.

#### 10.5.1.4 Far-end defects

- *Far-end Loss Of Signal (flos)* defect occurs when a *los* defect detected at the far end is reported in four or more out of six contiguously received far-end *los* indicator reports. A *flos* defect terminates when less than two far-end *los* indicators are reported out of six contiguously received reports.
- *Far-end Remote Defect Indication (frdi)* defect occurs when a *sef* defect detected at the far end is reported. A remote defect indication (*rdi*) defect terminates when the received report on *sef* is set to "0".

#### 10.5.1.5 Near-end failures

- *Loss of Signal (LOS)* failure is declared after  $TS1 = 2.5 \pm 0.5$  s of contiguous *los* defect, or, if *los* defect is present when the criteria of *LOF* failure declaration have been met. A *LOS* failure is cleared after  $TS2 = 10 \pm 0.5$  s of no *los* defect.
- *Loss of Frame (LOF)* failure is declared after  $TF1 = 2.5 \pm 0.5$  s of contiguous *sef* defect, except when a *los* defect or failure is present. A *LOF* failure is cleared when *LOS* failure is declared, or after  $TF2 = 10 \pm 0.5$  s of no *sef* defect.

#### 10.5.1.6 Far-end failures

- *Far-end Loss of Signal (FLOS)* failure is declared after  $TS1 = 2.5 \pm 0.5$  s of contiguous *flos* defect is reported, or, if *flos* defect is reported when the criteria for *LOF* failure declaration have been met. A *FLOS* failure is cleared after  $TS2 = 10 \pm 0.5$  s of no *flos* defect.



- *Far-end Remote Failure Indication (FRFI)* failure is declared after  $TR1 = 2.5 \pm 0.5$  s of contiguous *rdi* defect, except when *flos* defect or *FLOS* failure is present. A *FRFI* is cleared when *FLOS* failure is declared, or after  $TR2 = 10 \pm 0.5$  s of no *rdi* defect.

### 10.5.2 Path-related primitives

All path-related primitives are defined separately for each dedicated path, terminated by the corresponding TPS-TC block. The anomalies, defects and failures are different for different protocols (ATM, PTM, etc.). For each protocol they should be represented by standard OAM indicators specified for that protocol. The indicators should be represented at the OAM interface of  $\gamma - O$  ( $\gamma - R$ ) reference points. The indicators should be coded "0" if no primitive has been registered during the monitoring period and shall be coded "1" to indicate that at least the primitive has been registered once during the monitoring period.

All the near-end primitives should be represented at both the VTU-O and VTU-R. The representation of far-end primitives at the VTU-O is mandatory. The representation of far-end primitives at the VTU-R is optional.

#### 10.5.2.1 Anomalies, defects and failures for ATM transport

The set of anomalies, defects and failures for the ATM transport shall comply with ITU-T Rec. I.432.1. The ATM transport anomalies, defects and failures shall be supported by the ATM-TC. If both the Fast and Slow ATM transport are established, the two corresponding ATM-TC channels shall be represented by two equal and independent sets of anomalies, defects and failures.

##### 10.5.2.1.1 Near-end anomalies

- *No Cell Delineation (ncd)* anomaly occurs immediately after ATM-TC start-up when ATM data are allocated to the buffer and as long as the cell delineation process operating on these data is in the HUNT or PRESYNC state (see G.4.3.3), as defined in ITU-T Rec. I.432.1. The *ncd* anomaly is optional. If *ncd* is not supported, the *ocd* anomaly shall be used instead.
- *Out of Cell Delineation (ocd)* anomaly occurs when ATM data is allocated to the buffer and the cell delineation process operating on these data transitions from SYNC to HUNT state, as defined in ITU-T Rec. I.432.1. An *ocd* anomaly terminates when the cell delineation process transitions from PRESYNC to SYNC state or when the *lcd* defect is entered.
- *Header Error Check (hec)* anomaly occurs when an ATM cell header error check fails.

##### 10.5.2.1.2 Far-end anomalies

- *Far-end No Cell Delineation (fncd)* anomaly occurs when either a *ncd* or an *ocd* anomaly is detected at the far end and reported by a *fncd* indicator. An *fncd* anomaly always occurs immediately after VTU start-up. An *fncd* anomaly terminates when the received *fncd* indicator is coded "0".
- *Far-end Out of Cell Delineation (focd)* anomaly occurs when an *ocd* anomaly is detected at the far end and reported by a *focd* indicator and no *fncd* anomaly is present. A *focd* anomaly terminates if the received *focd* indicator is coded "0". Indication of *focd* is optional.
- *Far-end Header Error Check (fhec)* anomaly occurs when *hec* anomaly is detected at the far end and reported by an *fhec* indicator. The *fhec* anomaly terminates when a received *fhec* indicator is set to "0". Indication of *fhec* is optional.

NOTE – Both the *focd* and *fhec* anomaly indication are optional, as neither is required by ITU-T Rec. I.432.1.

**10.5.2.1.3 Near-end defects**

- *Loss of Cell Delineation (lcd)* defect occurs when at least one *ocd* anomaly is present in each of 4 consecutive superframes and no *sef* defect is present. An *lcd* defect terminates when no *ocd* anomaly is present in 4 consecutive superframes.

**10.5.2.1.4 Far-end defects**

- *Far-end Loss of Cell Delineation (flcd)* defect occurs when a *lcd* defect is detected at the far end. An *flcd* defect occurs when a *focd* anomaly is present or a *fned* anomaly is present in each of 4 consecutive superframes and no *rdi* defect is present. A *flcd* defect terminates if neither *focd* nor *fned* anomaly is present in 4 consecutive superframes.

**10.5.2.1.5 Near-end failures**

- *No Cell Delineation (NCD)* failure is declared when a *ned* anomaly persists for more than  $2.5 \pm 0.5$  s after the start of steady-state transmission. An *NCD* failure terminates when no *ned* anomaly is present for more than  $10 \pm 0.5$  s.
- *Loss of Cell Delineation (LCD)* failure is declared when a *lcd* defect persists for more than  $2.5 \pm 0.5$  s. A *LCD* failure terminates when no *lcd* defect is present for more than  $10 \pm 0.5$  s.

**10.5.2.1.6 Far-end failures**

- *Far-end No Cell Delineation (FNCD)* failure is declared when a *fned* anomaly has persisted for more than  $2.5 \pm 0.5$  s. A *FNCD* failure terminates when no *fned* anomaly is present for more than  $10 \pm 0.5$  s.
- *Far-end Loss of Cell Delineation (FLCD)* failure is declared when a *flcd* defect has persisted for more than  $2.5 \pm 0.5$  s. A *FLCD* failure terminates when no *flcd* anomaly is present for more than  $10 \pm 0.5$  s.

**10.5.2.2 Anomalies, defects and failures of STM transport**

For further study.

**10.5.2.3 Anomalies, defects and failures for PTM transport**

The PTM transport anomalies, defects and failures shall be supported by the PTM-TC. If both the Fast and Slow PTM channels are established, the two corresponding PTM-TC shall be represented by two equal and independent sets of anomalies, defects and failures.

**10.5.2.3.1 Near-end anomalies**

- *Packet Error (per)* anomaly occurs when packet error is indicated by an FCS count.

**10.5.2.3.2 Far-end anomalies**

- *Far-end Packet Error (fper)* is declared when *per* anomaly is detected at the far end and reported by an *fper* indicator. The anomaly terminates when the received *fper* indicator is coded "0".

**10.5.2.3.3 Near-end defects**

- *Packet Error (PER)* defect occurs if packet error anomaly persists for more than TD4\_1 s. The *PER* defect terminates when no *per* anomaly is present in more than TD4\_2 s.

NOTE – The values of TD4 are TBD.

**10.5.2.3.4 Far-end defects**

- *Far-end Packet Error (FPER)* defect is declared when *PER* defect is detected at the far end reported by an *FPER* indicator. The *FPER* defect terminates when the received *FPER* indicator is coded "0".



### 10.5.3 Power-related primitives

Power-related primitives shall be represented by the corresponding indicators. The indicators shall be coded "0" if no power primitive has been registered during the monitoring period and shall be coded "1" to indicate that a power primitive has been registered during the monitoring period.

The near-end primitives shall be represented at both the VTU-O and VTU-R. The far-end primitives shall be represented at the VTU-O.

#### 10.5.3.1 Near-end primitives

- *Loss of Power (lpr)* primitive occurs when the VTU power supply (mains) voltage drops below the manufacturer-determined level required for proper VTU operation. An *lpr* primitive terminates when the power level exceeds the manufacturer-determined minimum power level.
- *Loss of Power (LPR)* failure is declared after  $TP1 = 2.5 \pm 0.5$  s of contiguous *lpr* primitive presence. A *LPR* failure is cleared after  $TP2 = 10 \pm 0.5$  s of no *lpr* primitive presence.
- *Power Off (PRO)* failure is declared when the VTU power switch is turned off by the operator. A *PRO* failure is cleared after the power switch is turned on. The *PRO* indicator is optional.

#### 10.5.3.2 Far-end primitives

- *Far-end Loss of Power (flpr)* primitive occurs when a *lpr* primitive is detected at the VTU-R and reported.
- *Far-end Loss of Power (FLPR)* failure is declared after the occurrence of a *flpr* primitive followed by  $TP1 = 2.5 \pm 0.5$  s of contiguous near-end *los* defect. A *FLPR* failure is cleared after  $TP2 = 10 \pm 0.5$  s of no near-end *los* defect.
- *Far-end Power-off (FPO)* failure occurs when a *PRO* failure detected at the VTU-R is reported. A *FPO* failure terminates after  $TP2$  s during which no *PRO* indicator is received and no near-end *los* defect is present. The *FPO* indicator is optional.

### 10.5.4 A minimum set of far-end indicators

Far-end indicators exchange the far-end primitives between the VTU-O and the VTU-R. A minimum set of required far-end indicators is presented in Table 10-5.

**Table 10-5/G.993.1 – A minimum set of far-end indicators**

Indicator	Description	Note
<b>Line-related</b>		
<i>febe_s</i>	Reports non-corrected errors in the received Slow data block at the far end	
<i>febe_f</i>	Reports non-corrected errors in the received Fast data block at the far end	
<i>ffec_s</i>	Reports corrected errors in the received Slow data block at the far end	
<i>ffec_f</i>	Reports corrected errors in the received Fast data block at the far end	
<i>flos</i>	Reports a loss of received signal energy at the far end	Applicable in the power-saving state
<i>rdi</i>	Reports severe frame errors at the far end	



**Table 10-5/G.993.1 – A minimum set of far-end indicators**

Indicator	Description	Note
<b>Power-related (System-related)</b>		
<i>flpr</i>	Reports the drop of supply voltage below the predefined level at the far end	Applicable in the power-saving state
<i>FPO</i>	Reports that the power switch was turned off at the far end	Optional. Applicable in the power-saving state
<b>ATM-path-related</b>		
<i>fncd</i>	Reports on a loss of cell delineation anomaly at the far end	
<i>fhec</i>	Reports on hec errors at the far end	Optional
<b>PTM-path-related</b>		
<i>FPER</i>	Reports on a persisting and significant packet errors at the far end	
<i>PLOS</i>	Reports on a persisting and significant packet loss at the far end	
<b>Other-path-related</b>		
TBD		

All indicators shall be sent periodically, when the system is in a *Steady-State Transmission state*, to update the information on far-end primitives. Indicators of *far-end loss of signal (flos)* and the *far-end power-related primitives (flpr, FPO)* shall also be transmitted when the system is in *Deactivated Power Saving (IDLE) state*. The transfer mechanism of the indicators is specified in 8.5.5.

### **10.5.5 Performance parameters**

The defined set of performance parameters shall describe both line-related and path-related parameters at the VTU-O and VTU-R.

#### **10.5.5.1 Line-related performance parameters**

The VDSL line-related performance parameters shall be calculated using the related anomalies as presented in 10.5.1.

#### **10.5.5.2 Path-related performance parameters**

The path-related performance parameters shall be calculated specifically for each applied service transport protocol separately, in accordance with the corresponding definition for that transport protocol. If the same transport protocol is used for both the fast and the slow paths, separate performance parameters for each should be calculated.

##### **10.5.5.2.1 ATM data path-related performance parameters**

The following near-end performance parameters shall be provided at the VTU-O and VTU-R:

- *HEC\_violation\_count*: The *HEC\_violation\_count* performance parameter is a count of the number of occurrences of *hec* anomaly;
- *HEC\_total\_cell\_count*: The *HEC\_total\_cell\_count* performance parameter is a count of the total number of cells passed through the cell delineation process operating on the fast data when in the SYNC state;

- *User\_total\_cell\_count*: The *User\_total\_cell\_count* performance parameter is a count of the total number of cells in the fast data path delivered at the  $\gamma$ -O (for the VTU-O) or  $\gamma$ -R (for the VTU-R) interface.

#### 10.5.5.2.2 STM data path-related performance parameters

#### 10.5.5.2.3 PTM data path-related performance parameters

NOTE – Performance parameters for other path types will be added as the relevant path type is specified in 9.1.1.

### 10.5.6 Testing parameters

The near-end testing parameters shall be provided at both the VTU-O and VTU-R; the far-end testing parameters shall be provided at the VTU-O only.

#### 10.5.6.1 Near-end test parameters

The following near-end test parameters shall be provided at the VTU-O and the VTU-R:

- *Loop Attenuation (ATN)* is the difference in dB between the power received at the near end and that transmitted from the far end. The ATN shall be reported for each of the used (receive direction) carriers in the range from 0 to 63.5 dB, with 0.5-dB steps.
- *Signal-to-Noise Ratio margin (SNR<sub>M</sub>)* expresses the modem's estimation of the maximum amount by which the receiver noise (internal and external) could be increased without causing the modem to fail the BER requirement (see 14.3). The *SNR<sub>M</sub>* shall be reported for each of the used (receive direction) carriers in the range from –31.75 dB to +31.75 dB, with 0.25-dB steps.

#### 10.5.6.2 Far-end test parameters

The following far-end test parameters shall be provided at the VTU-O:

- *Far-end Loop Attenuation (FATN)*: The far-end attenuation is measured at the VTU-R and reported back to the VTU-O. The *FATN* shall be reported in the range from 0 dB to 63.75 dB, with 0.25-dB steps. Byte number 0x00 of VTU-R data register 0x06 shall contain the average *FATN* of all of the used downstream carriers. Optionally, the *FATN* per downstream band may be provided in byte numbers 0x01 thru 0xFF.
- *Far-end Signal-to-Noise Ratio margin (FSNR<sub>M</sub>)*: The far-end signal-to-noise ratio margin is measured at the VTU-R and reported back to the VTU-O. The *FSNR<sub>M</sub>* shall be reported in the range from –31.75 dB to +31.75 dB, with 0.25-dB steps. Byte number 0x00 of VTU-R data register 0x07 shall contain the average *FSNR<sub>M</sub>* of all of the used downstream carriers. Optionally, the *FSNR<sub>M</sub>* per downstream band may be provided in byte numbers 0x01 thru 0xFF.

NOTE – The *ATN* and *SNR<sub>M</sub>* testing parameters should be updated and provided "on-demand" at any time following the initialization of the system. There is no requirement to continuously monitor them.

## 10.6 VDSL Overhead Channel (VOC)

### 10.6.1 VOC bandwidth

A VDSL overhead control channel shall be included to support overhead functions. The raw VOC channel rate shall be  $8f_sV$  kbit/s with  $f_s$  the DMT symbol rate in kHz (see 9.2.2) and  $V$  is the number of bytes per frame that is reserved for VOC transport (see Table 8-3). The mechanism used to support the VOC channel is described in detail in 10.6.2.

### 10.6.2 VOC protocol

All VOC messages shall be transmitted five consecutive times to improve the probability of proper reception and decoding. A transceiver unit shall only act on a VOC message if it has received three



identical messages in a time period spanning five of that particular message. When an unrecognizable command is received (no three identical in a sequence of five), no action shall be taken.

Between two consecutive messages (i.e., a repetition of five), at least 20 idle bytes shall be transmitted. The idle bytes shall have the value 0x00.

### **10.6.3 High-level on-line adaptation**

#### **10.6.3.1 Bit swapping**

Bit swapping enables a VDSL system to change the number of bits assigned to a sub-channel, or change the transmit energy of a sub-carrier without interrupting the data flow.

Either VTU may initiate a bit swap. The swapping procedures in the upstream and downstream directions shall be independent and may take place during the same set of superframes. The "receiver" is defined as the modem that initiates the bit swap. It shall transmit the bit-swap request message and receive the bit-swap acknowledge message. The "transmitter" receives the bit-swap request and shall transmit the bit-swap acknowledge.

There shall be a maximum of one outstanding bit-swap request at any time in downstream. There shall be a maximum of one outstanding bit-swap request at any time in upstream.

Bit swap is a mandatory feature.

#### **10.6.3.2 Bit-swap channel**

Bit swaps shall be conducted using the VOC channel, using the protocol described in 10.6.2. Consequently, all bit-swap messages shall be repeated five consecutive times over the VOC channel.

#### **10.6.3.3 Bit-swap coordination**

Bit swapping shall be conducted using synchronized counters at the VTU-O and VTU-R. The counters shall increment by one after each bit-swap frame interval. A bit-swap frame interval is defined as the duration of 16 DMT symbols. The counters shall be started and incremented as follows:

- The VTU-O and VTU-R transmitters shall start their counters immediately after transitioning from initialization to steady-state operation. The value of the counter for the first superframe shall be zero;
- Each transmitter shall increment its counter after transmitting each bit-swap frame;
- Correspondingly, each receiver shall start its counter immediately after transitioning from initialization to steady state, and shall then increment it after receiving each bit-swap frame.

Any form of restart that requires a transition from initialization to steady-state shall reset the counters.

Counting of bit-swap frames shall be performed modulo 256.

#### **10.6.3.4 Bit-swap request**

Upon detecting SNR degradation in one or more sub-channels, the receiver shall initiate a bit swap by sending a bit-swap request back to the transmitter via the VOC channel. It shall be up to the receiver to determine what is considered to be a degradation. This request tells the transmitter which sub-channels are to be modified. The bit-swap request message shall contain the following:

- a VOC message header consisting of eight binary ones to indicate the ensuing bit-swap request;
- four message fields, each of which shall consist of an eight-bit command followed by a related 12-bit sub-channel index. Valid eight-bit commands for the bit-swap message shall

be as shown in Table 10-6. The 12-bit sub-channel index is counted from low to high frequencies with the lowest frequency sub-carrier assigned the number zero.

**Table 10-6/G.993.1 – Bit-swap request commands**

Value	Interpretation
00000000	Do nothing
00000001	Increase the allocated number of bits by one
00000010	Decrease the allocated number of bits by one
00000011	Change the transmitted power by the factor +1 dB
00000100	Change the transmitted power by the factor +2 dB
00000101	Change the transmitted power by the factor +3 dB
00000110	Change the transmitted power by the factor –1 dB
00000111	Change the transmitted power by the factor –2 dB
00001xxx	Reserved for vendor-specific commands

For a  $g_i$  update with  $\Delta$  dB, the new value of  $g_i$  shall be calculated as:

$$g_i' = 1/512 \times \text{round}(512 g_i 10^{\Delta/20})$$

The bit-swap request message (that is, the header plus the four message fields, a total of 11 bytes) is transmitted five consecutive times.

#### 10.6.3.5 Bit-swap acknowledge

After a VTU (the transmitter) has received three identical bit swap request messages within the span of five message-times, the transmitter shall act on the request. Within 400 ms of receiving the bit swap request, the transmitter shall first send a bit-swap acknowledge, which shall contain the following:

- a VOC message header containing eight binary ones, indicating receipt of the request message;
- one message field that consists of eight binary ones followed by the eight-bit bit-swap frame counter number, which indicates after how many bit-swap frame intervals should the bit swap occur. This number shall be at least 200 greater than that of the value of the counter when the bit-swap request was received. This corresponds to a minimum wait time of 800 ms.

Specifically, the new bit or transmit energy table(s), or both, shall take effect starting from the first symbol of the VDSL bit-swap frame specified by the bit-swap frame counter number. In other words, if the bit-swap frame counter number contained in the bit-swap acknowledge message is  $n$ , then the new table(s) shall take effect starting from the first applicable symbol of the  $n$ th bit-swap frame.

When the transmitter correctly receives the message, but is unable to perform the requested action, it shall transmit an Unable-To-Comply message (UTC). This message shall consist of a single byte with value 0xF0 (repeated five times as described in 10.6.2).

#### 10.6.3.6 Bit swap – Receiver

The receiver shall start a timeout of 500 ms from the moment it sends the bit-swap request. When no acknowledgement has been received in this timeout interval, the receiver can retransmit the request. After a number of unsuccessful retries, the modem can take vendor discretionary actions to accomplish bit swap.



The receiver shall act on a bit-swap request when it has received three identical bit-swap acknowledge messages within the span of five message-times. The receiver shall then wait until the bit-swap frame counter equals the value specified in the bit-swap acknowledge. Then, beginning with the first symbol in the next bit-swap frame, the receiver shall:

- change the bit assignment of the appropriate sub-channels and, if necessary, perform tone re-ordering based on the new sub-channel bit assignment;
- update applicable receiver parameters of the appropriate sub-channels to account for any changes in their transmitted energy.

#### 10.6.3.7 Bit swap – Transmitter

After the bit-swap acknowledge has been transmitted, the transmitter shall wait until the bit-swap frame counter equals the value specified in the bit-swap acknowledge. Then, beginning with the first symbol in the next bit-swap frame, the transmitter shall:

- change the bit assignment of the appropriate sub-channels and, if necessary, perform tone re-ordering based on the new sub-channel bit assignment;
- change the transmitter energy in the appropriate sub-channels by the desired factors.

#### 10.6.3.8 Express swapping

Express swapping enables a VDSL system to change the number of bits assigned to a sub-channel, or change the transmit energy of a sub-carrier *without* any hand-shaking acknowledgements. Express swapping is an option. It is introduced to augment the performance of bit swapping.

Express swapping:

- increases the execution speed for a swap significantly;
- requires the use of a more sophisticated receiver for the monitoring of the received signal to determine if an express-swap request was executed correctly.

#### 10.6.3.9 Express swap request

Upon detecting changes in the sub-channels' SNR, the receiver shall initiate an express swap by sending an express-swap request back to the transmitter via the VOC channel.

An express-swap command shall be sent only *once* and allows alteration of the bit distribution (or gain distribution) on  $n$  tones through the transmission of a command as shown in Table 10-7.

**Table 10-7/G.993.1 – Express swap request command**

VOC message headers	VOC message field total length including message header (bytes)	Interpretation
11110010	$2.5n + 5$ for $n$ even $2.5n + 4.5$ for $n$ odd	Implement express bit-swap request for a total of $n$ tones on the <i>next</i> bit-swap frame
11110011	$2.5n + 5$ for $n$ even $2.5n + 4.5$ for $n$ odd	Implement express bit-swap request for a total of $n$ tones on the <i>next-to-next</i> bit-swap frame

An express-swap request command shall contain the following:

- a VOC message header consisting of either the pattern 11110010 or 11110011 to indicate the ensuing express-swap request. The header pattern 11110010 means the express swap should be executed in the next bit-swap frame while the pattern 11110011 means the express swap should be implemented in the next-to-next bit-swap frame;
- a 12-bit message field to indicate the total number of tones ( $n$ ) whose bit or gain distributions (or both) need to be updated;

- $n$  message fields, each of which shall be 20 bits long. The first 12 bits indicate the sub-channel index. In the next 8 bits, the upper nibble of 4 bits shall encode the new absolute number of bits, which is a number between 0 and a maximum of 15, according to 0000 for no bits, 0010 for 2 bits, up to 1111 for 15 bits. The lower nibble of 4 bits, with the most significant bit as the sign bit, shall encode the relative gain by a 2's complement 4-bit quantity between  $-4$  and  $+3.5$  dB (with 0.5-dB increments);
- 4 dummy bits if  $n$  is even;
- an internal 16-bit CRC protection for error detection.

Table 10-8/G.993.1 – Express swap request command

Message header	ES control	1st tone index	1st tone total bits/gain	..	nth tone index	nth tone total bits/gain	Dummy bits	CRC
1111001x (1 byte)	Tone count (12 bits)	Tone number (12 bits)	# of bits/gain (1 byte)		tone number (12 bits)	# of bits/gain (1 byte)	0 to $n$ odd 4 to $n$ even	16 bits

There is no Express-Swap Acknowledge command. The receiver that initiates an express swap shall be responsible for monitoring the returned DMT signal to determine if the command has been implemented by the transmitter. If the swap has not been detected on the correct superframe, then the receiver assumes the request is not implemented by the transmitter. The express-swap initiating DMT receiver may then choose to repeat the express-swap command, to send another VOC command, or to retrain.

The CRC at the end of the command shall follow the same byte CRC protocol as used in initialization for confirmation of correct receipt of message fields. The polynomial used is  $g(Z) = Z^{16} + Z^{12} + Z^{15} + 1$  where  $Z$  is an advance of one bit period. The CRC shall be calculated over all bits in the express-swap request command.

## 11 Performance requirements

### 11.1 Error performance requirements

The G.993.1 system shall operate with a noise margin of at least +6 dB and a long-term bit error ratio of  $<1$  in  $10^7$ .

### 11.2 Latency requirements

The latency of fast channel averaged over upstream and downstream shall be no greater than 1 ms, measured between the  $\alpha$  and  $\beta$ -interfaces.

### 11.3 Impulse noise immunity requirements

G.993.1 systems shall provide protection against disturbance from impulse noise.

Furthermore, they shall provide at least two levels of protection. The level of protection shall be set and controlled via the NMS as specified in 10.4.

The lowest level of protection is required to support latency sensitive services such as voice, while the highest level is required to support burst error sensitive services such as entertainment video.

In a high latency VDSL channel, at the maximum delay of 20 ms, the bit error probability specified in 11.1 should not be exceeded when the path is subject to a noise burst of up to 500  $\mu$ s.



Optionally, it is permitted to operate with a maximum delay of up to 10 ms when subject to a noise burst of duration up to 250  $\mu$ s.

## 12 Initialization

### 12.1 Handshake – VTU-O

The detailed procedures for handshake at the VTU-O are defined in ITU-T Rec. G.994.1. A VTU-O, after power-up, loss of signal or recovery from errors during the initialization procedure, shall enter the initial G.994.1 state C-SILENT1. The VTU-O may transition to C-TONES under instruction of the network operator. The VTU-O may transition to the Initialization Reset Procedure under instruction from the network. From either state, operation shall proceed according to the procedures defined in ITU-T Rec. G.994.1.

If G.994.1 procedures select ITU-T Rec. G.993.1 as the mode of operation, the VTU-O shall transition to G.993.1 at the conclusion of G.994.1 operation. If G.994.1 procedures select Annex I/G.993.1 as the mode of operation, the VTU-O shall transition to Annex I/G.993.1 at the conclusion of G.994.1 operation.

#### 12.1.1 CL messages

A VTU-O wishing to indicate G.993.1 capabilities in a G.994.1 CL message shall do so by setting to ONE the SPar(1) G.993.1 bit as defined in Table 11.0.4/G.994.1. The NPar(2) (Table 11.59/G.994.1) and SPar(2) (Table 11.60/G.994.1) fields corresponding to the "G.993.1" Level 1 bit are defined in Tables 12-1 and 12-2, respectively. For each G.993.1 SPar(2) bit set to ONE, a corresponding NPar(3) field shall also be present (see Tables 11.60.x.x in 9.4/G.994.1).

**Table 12-1/G.993.1 – VTU-O CL message NPar(2) bit definitions**

<b>G.994.1 NPar(2) bit</b>	<b>Definition</b>
OptUp	If set to ONE, signifies that the VTU-O can be configured to use the optional band from 25 to 138 kHz for upstream (VTU-R $\rightarrow$ VTU-O) transmission.
OptDn	If set to ONE, signifies that the VTU-O can be configured to use the optional band from 25 to 138 kHz for downstream (VTU-O $\rightarrow$ VTU-R) transmission.
PSDRed	If set to ONE, signifies that the VTU-O and VTU-R shall be configured to reduce the PSD in the frequency region below 1.104 MHz.
PTM	If set to ONE, signifies that the VTU-O can be configured for PTM transport.
ATM	If set to ONE, signifies that the VTU-O can be configured for ATM cell transport. (Annex G)
EOC-Clear	If set to ONE, signifies that the VTU-O supports transmission and reception of G.997.1 OAM frames.

At least one of the PTM and ATM bits shall be set to ONE in a CL message.

**Table 12-2/G.993.1 – VTU-O CL message SPar(2) bit definitions**

<b>G.994.1 SPar(2) bit</b>	<b>Definition</b>
Used bands in upstream	The use of this bit is optional. If set to ONE, indicates the used upstream bands. The optional band between 25 kHz to 138 kHz shall not be included.
Used bands in downstream	The use of this bit is optional. If set to ONE, indicates the used downstream bands. The optional band between 25 kHz to 138 kHz shall not be included.
IDFT/DFT size	Always set to ONE in a CL message. Indicates the maximum IDFT/DFT size that VTU-O can support. The value shall be present in the corresponding NPar(3) field.
Initial length of CE	If set to ZERO, it signifies that the VTU-O can support only the mandatory cyclic extension length of $40 \cdot 2^n$ for a number of tones equal to $256 \cdot 2^n$ . If set to ONE in a CL message, it indicates the initial sample length of the cyclic extension that VTU-O can support. It also signifies that the VTU-O can support CE lengths other than the mandatory length. The value shall be present in the corresponding NPar(3) field.  If one of the modems supports only the mandatory value, then this value shall be used.
RFI bands	The use of this bit is optional. If set to ONE, indicates that the start and stop frequencies of the RFI bands will be transmitted.

**12.1.2 MS messages**

A VTU-O selecting G.993.1 mode of operation in a G.994.1 MS message shall do so by setting to ONE the SPar(1) G.993.1 bit as defined in Table 11.0.4/G.994.1. The NPar(2) (Table 11.59/G.994.1) and SPar(2) (Table 11.60/G.994.1) fields corresponding to this bit are defined in Tables 12-3 and 12-4, respectively. For each SPar(2) bit set to ONE, a corresponding NPar(3) field shall also be present (see Tables 11.60.x.x in 9.4/G.994.1).

**Table 12-3/G.993.1 – VTU-O MS message NPar(2) bit definitions**

<b>NPar(2) bit</b>	<b>Definition</b>
OptUp	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It signifies that the band between 25 kHz and 138 kHz shall be used for upstream (VTU-R → VTU-O) transmission.
OptDn	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It signifies that the band between 25 kHz and 138 kHz shall be used for downstream (VTU-O → VTU-R) transmission.
PSDRed	If set to ONE, signifies that the VTU-O and VTU-R shall be configured to reduce the PSD in the frequency region below 1.104 MHz.
PTM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for PTM transport.
ATM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for ATM cell transport.
EOC-Clear	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R may transmit and receive G.997.1 OAM frames.



If both bits "OptUp" and "OptDn" are enabled in the CL and CLR message, one and only one of the bits shall be set to ONE in an MS message sent from the VTU-O, and the use of the band between 25 kHz and 138 kHz is at the VTU-O's discretion. If the VTU-O and VTU-R have no common usage of the optional band, both bits shall be set to ZERO in an MS message sent from the VTU-O.

One and only one of the PTM and ATM bits shall be set to ONE in an MS message sent from the VTU-O. If both bits are enabled in the CL and CLR message, the PTM or ATM selection is at the VTU-O's discretion.

**Table 12-4/G.993.1 – VTU-O MS message SPar(2) bit definitions**

<b>SPar(2) bit</b>	<b>Definition</b>
Used bands in upstream	Always set to ZERO in an MS message.
Used bands in downstream	Always set to ZERO in an MS message.
IDFT/DFT size	Always set to ONE in an MS message. Indicates the maximum IDFT/DFT size that both the VTU-O and VTU-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of <i>CE</i>	Set to ZERO if and only if this bit was set to ZERO in the last previous CL message or the last previous CLR message, or both. It signifies that both VTU-O and VTU-R shall use only the mandatory cyclic extension length.  Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It indicates the initial sample length of the cyclic extension. It also signifies that both VTU-O and VTU-R can support CE lengths other than the mandatory length. The value shall be given in the corresponding NPar(3) field.
RFI bands	Always set to ZERO in an MS message.

## **12.2 Handshake – VTU-R**

The detailed procedures for handshake at the VTU-R are defined in ITU-T Rec. G.994.1. After power-up, loss of signal, or recovery from errors during the initialization procedure, a VTU-R shall enter the initial G.994.1 state R-SILENT0. Upon command from the host controller, the VTU-R shall initiate handshaking by transitioning from the R-SILENT0 state to the G.994.1 R-TONES-REQ state. Operation shall then proceed according to the procedures defined in ITU-T Rec. G.994.1.

If G.994.1 procedures select G.993.1 as the mode of operation, the VTU-R shall transition to G.993.1 at the conclusion of G.994.1 operation. If G.994.1 procedures select Annex I/G.993.1 as the mode of operation, the VTU-R shall transition to Annex I/G.993.1 at the conclusion of G.994.1 operation.

### **12.2.1 CLR messages**

A VTU-R wishing to indicate G.993.1 capabilities in a G.994.1 CLR message shall do so by setting to ONE the G.993.1 SPar(1) bit as defined in Table 11.0.4/G.994.1. The NPar(2) (Table 11.59/G.994.1) and SPar(2) (Table 11.60/G.994.1) fields corresponding to the G.993.1 SPar(1) bit are defined in Tables 12-5 and 12-6, respectively. For each Level 2 SPar(2) bit set to ONE, a corresponding NPar(3) field shall also be present (see Tables 11.60.x.x in 9.4/G.994.1).

**Table 12-5/G.993.1 – VTU-R CLR message NPar(2) bit definitions**

<b>NPar(2) bit</b>	<b>Definition</b>
OptUp	If set to ONE, signifies that the VTU-R is capable of using the band between 25 kHz and 138 kHz and that the band can be used for the upstream (VTU-R → VTU-O) transmission.
OptDn	If set to ONE, signifies that the VTU-R is capable of using the band between 25 kHz and 138 kHz and that the band can be used for the downstream (VTU-O → VTU-R) transmission.
PSDRed	Shall be set to ONE.
PTM	If set to ONE, signifies that the VTU-R can be configured for PTM transport.
ATM	If set to ONE, signifies that the VTU-R can be configured for ATM cell transport.
EOC-Clear	If set to ONE, signifies that the VTU-R supports transmission and reception of G.997.1 OAM frames.

At least one of the PTM and ATM bits shall be set to ONE in a CLR message.

**Table 12-6/G.993.1 – VTU-R CLR message SPar(2) bit definitions**

<b>SPar(2) bit</b>	<b>Definition</b>
Used bands in upstream	Always set to ZERO in a CLR message.
Used bands in downstream	Always set to ZERO in a CLR message.
IDFT/DFT size	Always set to ONE in a CLR message. Indicates the maximum IDFT/DFT size that VTU-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of <i>CE</i>	<p>If set to ZERO, it signifies that the VTU-R can support only the mandatory cyclic extension length of <math>40 \cdot 2^n</math> for a number of tones equal to <math>256 \cdot 2^n</math>.</p> <p>If set to ONE in a CLR message, it indicates the initial sample length of the cyclic extension that VTU-R can support. It also signifies that the VTU-R can support CE lengths other than the mandatory length. The value shall be present in the corresponding NPar(3) field.</p> <p>If one of the modems supports only the mandatory value, then this value shall be used.</p>
RFI bands	Always set to 0 in a CLR message.

### 12.2.2 MS messages

A VTU-R selecting G.993.1 mode of operation in a G.994.1 MS message shall do so by setting to ONE the G.993.1 SPar(1) bit as defined in Table 11.0.4/G.994.1. The NPar(2) (Table 11.59/G.994.1) and SPar(2) (Table 11.60/G.994.1) fields corresponding to this bit are defined in Tables 12-7 and 12-8, respectively. For each G.993.1 SPar(2) bit set to ONE, a corresponding NPar(3) field shall also be present (see Tables 11.60.x.x in 9.4/G.994.1).



**Table 12-7/G.993.1 – VTU-R MS message NPar(2) bit definitions**

<b>NPar(2) bit</b>	<b>Definition</b>
OptUp	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It signifies that the band between 25 kHz and 138 kHz shall be used for upstream (VTU-R → VTU-O) transmission.
OptDn	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It signifies that the band between 25 kHz and 138 kHz shall be used for downstream (VTU-O → VTU-R) transmission.
PSDRed	If set to ONE in a CL message, it shall be set to ONE in an MS message and signifies that the VTU-O and VTU-R shall be configured to reduce the PSD in the frequency region below 1.104 MHz.
PTM	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for PTM transport.
ATM	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for ATM cell transport.
EOC-Clear	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R may transmit and receive G.997.1 OAM frames.

If both bits "OptUp" and "OptDn" are enabled in the CL and CLR message, one and only one of the bits shall be set to ONE in an MS message sent from the VTU-R, and the use of the band between 25 kHz and 138 kHz shall be at the VTU-R's discretion. If the VTU-O and VTU-R have no common usage of the optional band, both bits shall be set to ZERO in an MS message sent from the VTU-R.

One and only one of the PTM and ATM bits shall be set to ONE in an MS message sent from the VTU-R. If both bits are enabled in the CL and CLR message, the PTM or ATM selection shall be at the VTU-R's discretion.

**Table 12-8/G.993.1 – VTU-R MS message SPar(2) bit definitions**

<b>SPar(2) bit</b>	<b>Definition</b>
Used bands in upstream	Always set to ZERO in an MS message.
Used bands in downstream	Always set to ZERO in an MS message.
IDFT/DFT size	Always set to ONE in an MS message. Indicates the maximum IDFT/DFT size that both the VTU-O and VTU-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of <i>CE</i>	Set to ZERO if and only if this bit was set to ZERO in the last previous CL message or the last previous CLR message, or both. It signifies that both VTU-O and VTU-R shall use only the mandatory cyclic extension length.  Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It indicates the initial sample length of the cyclic extension. It also signifies that both VTU-O and VTU-R can support CE lengths other than the mandatory length. The value shall be given in the corresponding NPar(3) field.
RFI bands	Always set to ZERO in an MS message.

### 12.2.3 MP messages

A VTU-R proposing G.993.1 mode of operation in a G.994.1 MP message shall do so by setting to ONE the G.993.1 SPar(1) bit as defined in Table 11.0.4/G.994.1. The NPar(2) (Table 11.59/G.994.1) and SPar(2) (Table 11.60/G.994.1) fields corresponding to this bit are defined in Tables 12-9 and 12-10, respectively. For each Level 2 SPar(2) bit set to 1<sub>b</sub>, a corresponding NPar(3) field shall also be present (see Tables 11.60.x.x in 9.4/G.994.1).

**Table 12-9/G.993.1 – VTU-R MP message NPar(2) bit definitions**

NPar(2) bit	Definition
OptUp	If set to ONE, signifies to propose to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission. In an MP message, only one of OptUp and OptDn may be set to ONE.
OptDn	If set to ONE, signifies to propose to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission. In an MP message, only one of OptUp and OptDn may be set to ONE.
PSDRed	If set to ONE signifies to propose to reduce the PSD in the frequency region below 1.104 MHz.
PTM	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Proposes that both VTU-O and VTU-R shall be configured for PTM transport.
ATM	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Proposes that both VTU-O and VTU-R shall be configured for ATM cell transport.
EOC-Clear	Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Proposes that both VTU-O and VTU-R may transmit and receive G.997.1 OAM frames.

One and only one of the PTM and ATM bits shall be set to ONE in an MP message sent from the VTU-R.

**Table 12-10/G.993.1 – VTU-R MP message SPar(2) bit definitions**

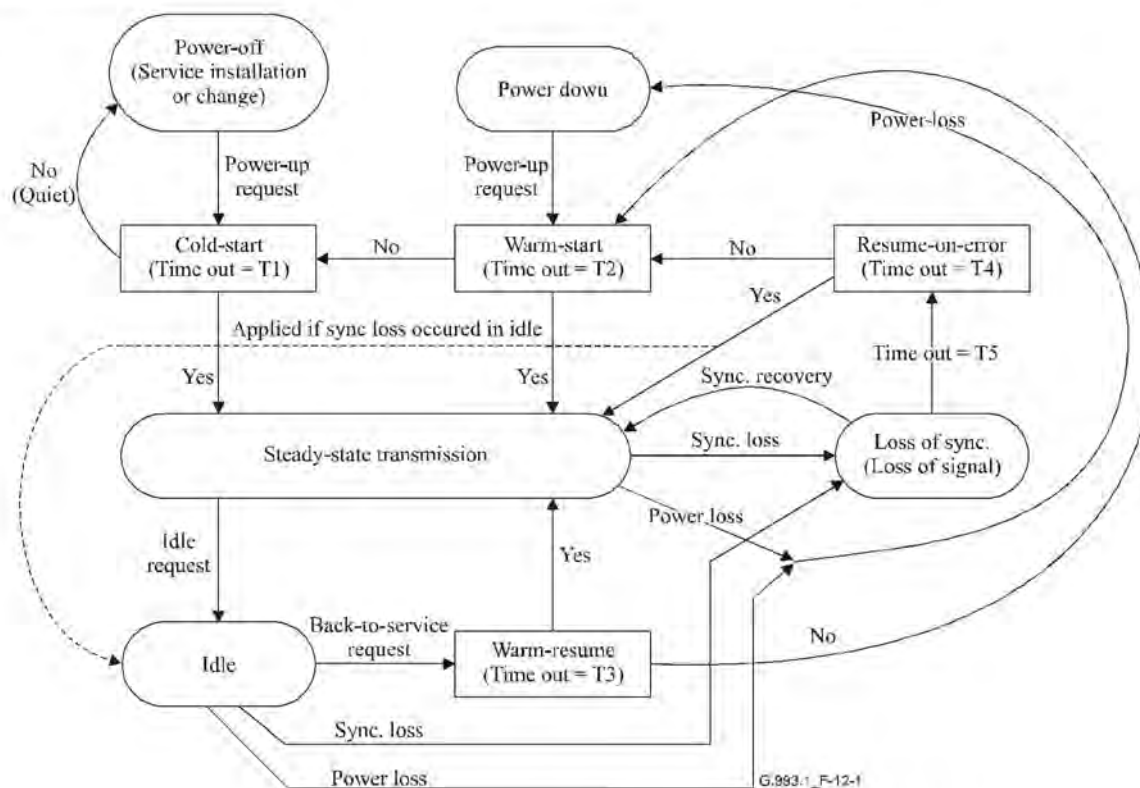
SPar(2) bit	Definition
Used bands in upstream	Always set to ZERO in an MP message.
Used bands in downstream	Always set to ZERO in an MP message.
IDFT/DFT size	Always set to ONE in an MP message. Indicates the maximum IDFT/DFT size that both the VTU-O and VTU-R can support. The value shall be present in the corresponding NPar(3) field.
Initial length of <i>CE</i>	Set to ZERO if and only if this bit was set to ZERO in the last previous CL message or the last previous CLR message, or both. It signifies that both VTU-O and VTU-R shall use only the mandatory cyclic extension length.  Set to ONE if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. It indicates the initial sample length of the cyclic extension. It also signifies that both VTU-O and VTU-R can support CE lengths other than the mandatory length. The value shall be given in the corresponding NPar(3) field.
RFI bands	Always set to ZERO in an MP message.



### 12.3 Link state and timing diagram

### 12.3.1 Overview

The VDSL link state and timing diagram is described in Figure 12-1. The diagram includes five states (rounded blocks), four procedures of link activation (rectangular blocks) and two types of link deactivation.



**Figure 12-1/G.993.1 – VDSL link state and timing diagram**

#### 12.3.1.1 States

The link State and Timing diagram shall contain the following five states:

- 1) *Power-off* is the initial state intended for service installation and modification prior to the first power-up process.
- 2) *Steady-State Transmission* is a state achieved after the link activation process is completed. In this state, the link shall transport user information with standard performance characteristics.
- 3) *Loss of Sync (Loss of Signal)* is a state achieved if transmission frame synchronization loss occurs (also as a result of signal energy loss or symbol timing loss). During this state the link is interrupted. The link shall return from this state back to *Steady-State Transmission* if frame synchronization is recovered in a short period of time (T5). Otherwise, the link shall be moved to perform the *Resume-on-Error* activation procedure.
- 4) *Power Down* is a state achieved after a guided power removal, power failure or *QUIET* deactivation at either the VTU-O or VTU-R. During this state the link is terminated. The link shall be moved from this state into the *Warm-Start* procedure by applying a Power-up request.

- 5) *Idle* state generates low crosstalk and reduced power consumption for the link when no broadband calls are in progress. After the VTU-O or VTU-R detects a broadband call wake-up signal (Back-to-Service request) from the network or from the CPE, respectively, a *Warm-Resume* procedure is executed.

NOTE – If the link connection is maintained during the *Idle* state, at least data frame synchronization, VOC transparency and Sync. Loss event monitoring should be provided. The user data channels and eoc transparency are optional. If the link connection is not maintained during the *Idle* state, the Sync. Loss event in the *Idle* state is not monitored.

#### **12.3.1.2 Activation procedures**

Either the VTU-R or the VTU-O shall be able to initiate the activation process. The activation process may be started by a power-up request, or after link interruption/deactivation. A successfully completed activation process makes the link ready for steady-state data communication.

##### **12.3.1.3 Cold start**

*Cold-Start* shall be applied after the first power-up or after an unsuccessful *Warm-Start* activation. If finished unsuccessfully, some changes in the installed service shall be made to simplify the link establishment.

NOTE – Unsuccessful *Cold-Start* activation usually occurs when the activated link environment (attenuation, noise etc.) cannot provide the desired service.

##### **12.3.1.4 Warm start**

*Warm-Start* shall be applied after an unsuccessful *Resume-on-Error* activation, or an unsuccessful *Warm-Resume* activation, or after either Power-down/Power failure or a link deactivation (*QUIET*) event. If *Warm-Start* fails, the *Cold-Start* activation is applied.

NOTE – Unsuccessful *Warm-Start* activation usually occurs after significant change of line characteristic (for example a connection to a new line with unknown parameters).

##### **12.3.1.5 Resume on error**

*Resume-on-Error* shall be applied after a link interruption due to loss of synchronization, which was not self-recovered during the defined time-out (T5). If *Resume-on-Error* fails, the *Warm-Start* activation is applied.

NOTE – Unsuccessful *Resume-on-Error* activation is usually due to a temporary change of noise conditions in the loop or due to modification of the transmission parameters.

##### **12.3.1.6 Warm resume**

*Warm-Resume* shall be applied on receipt of a broadband call wake-up signal (Back-to-Service request command) if the link resides in the *Idle* mode. If *Warm-Resume* fails, the *Warm-Start* activation is applied.

NOTE 1 – Unsuccessful *Warm-Resume* activation is usually due to a temporary change of noise conditions in the loop.

NOTE 2 – Back-to-Service request command may be applied at both the VTU-O and the VTU-R.

#### **12.3.2 Activation process**

Any of the defined activation processes conceptually includes the following steps:

- 1) Upstream and Downstream PMD sub-layer synchronization;
- 2) Upstream and Downstream PMS-TC sub-layer synchronization;
- 3) Open the steady-state data communication between the VTU-O and VTU-R (TPS-TC sublayer activation).



### 12.3.3 Deactivation procedure

The deactivation process may be initiated at either the VTU-O or VTU-R by special control signals. Both the VTU-O and VTU-R should support the following two types of link deactivation:

- 1) *QUIET* shall terminate the link. *QUIET* shall be applied if power failure occurs, or if a transceiver restart is desired, or as a part of the power-down process. *QUIET* may be initiated while the link resides in any state or during any activation process. In any case, except the Cold-Start, after *QUIET* deactivation the link shall be moved into the Power-Down state. *QUIET* deactivation during the Cold-Start move the link into the initial (Power-off) state.
- 2) *Idle Request* shall move the link into the *Idle* state. *Idle Request* may be applied on receipt of a broadband call release while the link resides in *Steady-State Transmission* state only.

NOTE – The *Warm-Resume* activation procedure is applied to return the link from the *Idle* state to a *Steady-State Transmission* state.

### 12.3.4 Delay to service

Delay to service is defined by the activation time, which equals the time interval from the beginning of the activation process until the link reaches the steady-state communication. The activation time shall not exceed the value of the time constants T1-T5, listed in Table 12-11.

**Table 12-11/G.993.1 – Activation time constants**

Process	Time constant	Maximum value [ms]
Cold-Start activation	T1	10000
Warm-Start activation	T2	5000
Warm-Resume activation	T3	100
Resume-on-Error activation	T4	300
Sync. Loss recovery	T5	200

## 12.4 Link activation/deactivation method

### 12.4.1 Overview

Initialization of a VTU-O/VTU-R pair includes a variety of tasks. The set of tasks consist of:

- Definition of a common mode of operation;
- Synchronization (sample clock alignment and symbol alignment);
- Transfer of frequency band allocation and PSD mask information from the VTU-O to the VTU-R;
- Channel identification;
- Noise identification;
- Calculation of bit loading and energy tables;
- Exchange of parameters (RS settings, interleaver parameters, VOC settings, bit loading and energy tables, ...).

Information such as the PSD mask, frequency band allocation, location of HAM & RFI bands, and bit-rate symmetry ratio is initially available at the VTU-O side. The initial value of the cyclic extension shall be exchanged during G.994.1 handshake, while timing advance (see 9.2.2 and 9.2.3.3) shall be set to the default value corresponding to a loop with a length of 1.5 km.

NOTE – Alternatively, a non-default value of the timing advance could be negotiated during G.994.1 handshake. This would allow communication on even longer loops (which may become feasible by using the optional frequency band for upstream transmission).

The timeline in Figure 12-2 provides an overview of the initialization protocol. Following the initial G.994.1 handshake procedure, a full duplex link between the VTU-O and the VTU-R is established. During the training phase, timing advance and upstream power back-off shall be refined. During the channel analysis and exchange state, the two modems shall measure the characteristics of the channel and agree on a contract that thoroughly defines the communication link.

VTU-O		
Activation: G.994.1 handshake procedures (see 12.4.3)	Training (see 12.4.4)	Channel analysis and exchange (see 12.4.6)
VTU-R		
Activation: G.994.1 handshake procedures (see 12.4.3)	Training (see 12.4.4)	Channel analysis and exchange (see 12.4.6)

**Figure 12-2/G.993.1 – Overview of initialization**

The transition between states or various operations shall be made following completion of the current state or the specific task rather than at fixed times.

During initialization (but not in the initial G.994.1 handshake phase), a SOC message channel shall exist in order to exchange information.

## **12.4.2 SOC protocol**

### **12.4.2.1 Message format**

The SOC shall use HDLC-like format with byte stuffing to delineate the messages as specified in ITU-T Rec. G.994.1. A reliable transmission shall be insured by using either an automatic repeat (AR) mode or a repeat request (RQ) mode. The maximum size of an HDLC frame shall be 1026 bytes (this also defines the maximum size of a SOC message segment). This is the size of the payload before octet stuffing and addition of any flags.

In the AR mode, the message encapsulated in the HDLC frame shall be automatically repeated. At least four idle flags (0x7E) shall be inserted between successive frames.

In the RQ mode, the messages encapsulated in HDLC frame shall be sent once. However, the VTU expecting the message shall have the possibility to request the remote side to repeat it by sending a REPEAT\_REQUEST message. This operation is necessary when the expected message has a wrong Check Sequence or when a timeout has expired. After two unsuccessful REPEAT\_REQUEST, the initialization shall be aborted. This means the initiating side will restart the G.994.1 handshake after a silent period. After a number of unsuccessful attempts, the modems shall stop all attempts. The number of attempts that is made before a final abort of the initialization shall be chosen by the initiating modem.

A SOC message shall contain an integer number of octets (8 bits per octet). The octets shall be sent least significant bit first. A message is subdivided in fields. A field can contain more than one byte. In this case, the field shall be split in bytes with the byte containing the most significant bits sent first. For example a field of 16 bits made of the bits  $m_{15}, \dots, m_0$  shall be segmented in a first byte  $B_0 = m_{15} \dots m_8$  and a second byte  $B_1 = m_7 \dots m_0$ . Some fields can be merged together to form a logical entity called a macro-field, such as "PSD descriptor", "Band descriptor".

The structure of an HDLC frame is illustrated in Figure 12-3.



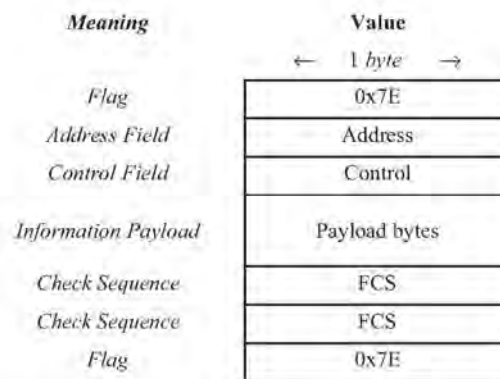


Figure 12-3/G.993.1 – Structure of an HDLC frame

**12.4.2.2 O/R-IDLE**

When the VTU-O is in the idle state (i.e., it has no SOC message to send), it shall send O-IDLE. The VTU-R shall send R-IDLE when in the idle state.

O-IDLE and R-IDLE correspond to the idle state of the HDLC protocol: 0x7E. This octet shall be transmitted repeatedly (i.e., there is no HDLC framing).

**12.4.2.3 O/R-REPEAT\_REQUEST**

This message shall request the remote side to repeat the last unacknowledged message.

NOTE – Due to the structure of the initialization sequence, all messages are acknowledged either by another message or by a symbol type transition. The information payload of the message shall consist of one octet: 0x55.

In AR mode, REPEAT\_REQUEST messages shall be ignored.

When messages are segmented, the REPEAT\_REQUEST message shall be able to ask for the retransmission of a particular segment of a message (see 12.4.2.6).

**12.4.2.4 Message codes**

The information payload of every SOC message shall start with a field (with a length of one byte) containing a unique code to identify the message and to allow fast and easy recognition of each SOC message. The message codes of all the messages sent during the initialization sequence are shown in Table 12-12 in hexadecimal notation. They are numbered in the order in which they appear. The messages originating at the VTU-O have the MSB equal to zero, the messages originating at VTU-R have MSB equal to one. Some one-byte messages have special codes.

**Table 12-12/G.993.1 – Message codes for the SOC messages**

SOC message	Message code
O/R-REPEAT_REQUEST	0x55 (Note)
R-ACK	0x00 (Note)
R-NACK	0xFF (Note)
O/R-ACK-SEG	0x0F (Note)
O-SIGNATURE	0x01
O-UPDATE <sub>n</sub>	0x02
O-MSG1	0x03
O-MSG2	0x04

**Table 12-12/G.993.1 – Message codes for the SOC messages**

SOC message	Message code
O-CONTRACT <sub>n</sub>	0x05
O-B&G	0x06
R-MSG1	0x81
R-MSG2	0x82
R-CONTRACT1	0x83
R-MARGIN <sub>n</sub>	0x84
R-B&G	0x85
NOTE – This is the entire payload of the message.	

**12.4.2.5 Message fields**

Typically, the information in a SOC message will be subdivided in a number of fields. The fields in every message will be given in detail below. It is possible that future versions will add extra fields to the ones already defined.

For reasons of backward compatibility, fields that are added in the future shall be appended to the currently defined fields.

For future safety, the current implementation shall ignore any extra fields following the currently defined fields in a message.

**12.4.2.6 Segmentation of messages**

Some messages could potentially be large, and even larger than the maximal allowed frame size of an HDLC frame (1026 octets). It shall therefore be possible to segment messages before transmission. In order to do this, all messages transmitted during initialization shall receive a number that counts the message. This number shall be stored in one byte and will wrap around in case of overflow. The value 0 shall not be used because it has a special meaning (see later). This means that 255 shall be followed by 1.

This "message index" shall be transmitted in the Address Field of the HDLC frame (see Figure 12-3). The message index allows to track lost messages and to request the retransmission of a particular message. The index shall initially be set to one and shall be incremented with one after the transmission of a message. The index shall not be incremented in case of a REPEAT-REQUEST. The counting of messages shall start when the transmission starts using RQ mode instead of automatic repeat (AR) mode.

A segmentation index (1 byte) shall be included in the Control Field of the HDLC frame. The four MSBs of this field shall indicate the number of segments that make up the total message. The four LSBs shall indicate the index of the current segment. For instance a value 0x93 indicates the third segment of a total of nine. In case the message is not segmented, the value of the field shall be 0x11.

The REPEAT-REQUEST message will behave differently from the other messages. The message index counter shall not be increased when a REPEAT-REQUEST message is sent. Also, the meaning of the message index and the segmentation index is different in this case.

The message index of the REPEAT-REQUEST message shall contain the message index of the message that should be retransmitted. The default value 0 indicates that the last unacknowledged message should be sent (this is why 0 shall never be used as message index for any other message). If this message contains several segments, only the last segment shall be retransmitted.



Likewise, the control field shall contain the segment that should be retransmitted. The Information payload of the REPEAT-REQUEST message shall still consist of one byte, containing the value 0x55.

In the initialization procedure, a transmitter should never send two consecutive messages without acknowledgement of the first message. It will always first receive some message from the other side before transmitting again. Therefore, an acknowledgement shall be sent for all but the last segment. Typically, the last segment signals the end of the message and it will therefore be acknowledged by the reply to this message. The ACK-SEG-message (see Table 12-12) shall be used to acknowledge the reception of the other segments. The ACK-SEG-message shall have its own message and segment index, which shall not refer to the segmented message that is being sent.

Once acknowledged, messages (or segments) are not expected to be retransmitted again. Also, a REPEAT-REQUEST that contains a number that is higher than the most recent value of the counter shall be ignored.

In AR mode, segmentation shall be done in the same way, but there will be no acknowledgements (ACK-SEG) between different segments of the same message. Segments shall be sent in order.

#### **12.4.3 G.994.1 handshake procedure**

The following parameters shall be transmitted with G.994.1:

- The size of the IDFT/DFT,  $N$ .  
NOTE – The size of the (I)FFT is twice the number of tones NSC.
- The initial length of the cyclic extension:  $CE = L_{CS} + L_{CP} - \beta$ .
- Flags indicating the use of the optional band, 25 ~ 138 kHz.

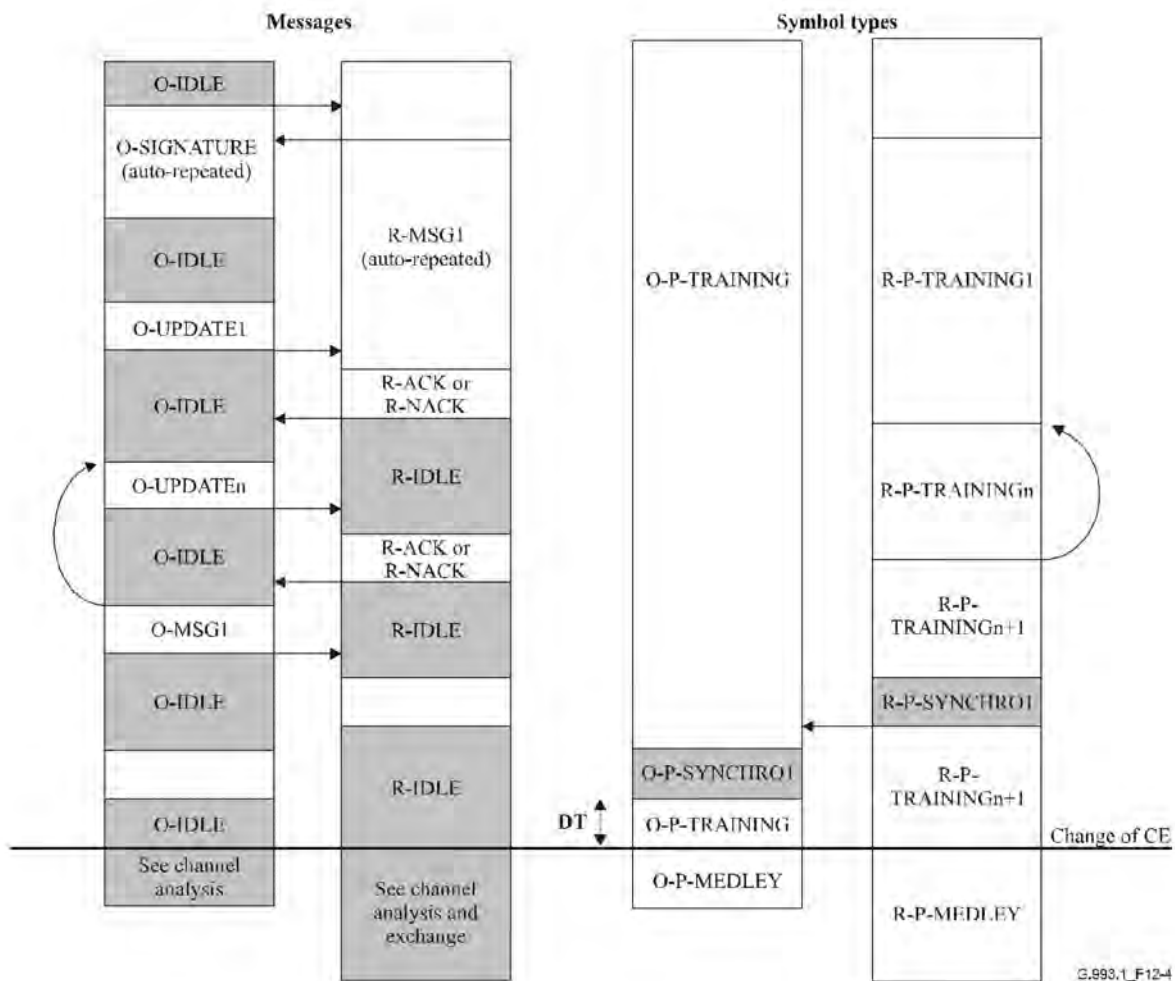
After the G.994.1 handshake phase, the VTU-O shall initiate the start of the training state.

#### **12.4.4 Training state**

Figure 12-4 gives an overview of the sequence of SOC messages and symbol types that are transmitted by VTU-O and VTU-R during the training phase.

##### **12.4.4.1 Sequence of messages and symbols during training state**

The sequence of message is illustrated in Figure 12-4.



**Figure 12-4/G.993.1 – Timeline of training phase**

The VTU-O shall initiate the start of the training phase by transmitting the symbol O-P-TRAINING. The message O-SIGNATURE shall be sent in parallel over the SOC channel (automatically repeated). Optionally, the message O-IDLE could be sent prior to transmission of O-SIGNATURE. This can for instance be useful for training the VTU-O echo canceller (see 12.4.5). During this first phase, the modems will synchronize.

Once the VTU-R is synchronized and has successfully decoded O-SIGNATURE, it shall transmit the symbol R-P-TRAINING. The SOC channel shall transmit the message R-MSG1. The VTU-O shall keep transmitting the O-P-TRAINING symbol and the O-SIGNATURE message. Optionally, it can switch to sending the O-IDLE messages, since the information in O-SIGNATURE has been already decoded correctly. During this phase, the VTU-O shall optimize timing advance and measure the received PSD at the VTU-O side. From then on, the VTU-O shall be able to initiate the next phase by transmitting the SOC message O-UPDATE1.

During this last phase, the transmit PSD of the VTU-R shall be tuned in an iterative procedure (if needed). The VTU-O shall send a change request over the SOC channel by transmitting the message O-UPDATEn. The VTU-R shall respond to each message by replying with a R-ACK<sub>n</sub> or R-NACK<sub>n</sub> SOC message. If R-ACK is transmitted, the VTU-R shall update the symbol R-P-TRAINING<sub>n</sub> to R-P-TRAINING<sub>n+1</sub> five symbols after sending R-ACK.

If R-NACK is transmitted, the VTU-O can continue the iterative process by sending O-UPDATEn+1, it can end the iterative process by sending O-MSG1 or it can abort the initialization.

This last phase shall be terminated by the VTU-O by sending the SOC message O-MSG1. Upon detection of O-MSG1, the VTU-R shall transmit the symbol R-P-SYNCHRO1. The VTU-O shall reply with O-P-SYNCHRO1. Both sides shall simultaneously update the *CE*, reset the quadrant scramblers and enter the next state (channel analysis and exchange) *DT* s after the last symbol of O-P-SYNCHRO1 has been sent. *DT* shall correspond to 15 DMT symbols (using the initial value for the cyclic extension).

NOTE 1 – If both VTU-O and VTU-R have agreed during G.994.1 handshake to use only the mandatory *CE* length, the *CE* length shall not be changed during the transition (and hence remain equal to the mandatory value; see 9.2.2).

NOTE 2 – If only the mandatory *CE* length is supported, the transitions in upstream and downstream need in principle not be simultaneous.

#### **12.4.4.2 Messages and symbols transmitted by VTU-O during the training state**

##### **12.4.4.2.1 SOC messages**

During the training state, the VTU-O will send the SOC messages O-SIGNATURE, O-UPDATEn and O-MSG1, as well as the idle message O-IDLE.

The way these messages are modulated on the transmit symbol is described in 12.4.4.2.2. The sequence in which the messages are sent is illustrated in Figure 12-4 and explained in more detail in 12.4.4.1.

##### **12.4.4.2.1.1 O-SIGNATURE**

This message shall contain the following nine fields:

- message descriptor;
- the bands used in downstream direction;
- the bands used in upstream direction;
- RFI bands;
- transmit PSD in downstream direction;
- whether PBO is performed using a maximum receive PSD or using an upstream PSD mask;
- the maximal transmit PSD in upstream direction;
- the reference PSD (see 9.2.4);
- the overall length of the window at the transmitter ( $\beta$ , see 9.2.2).

The content of O-SIGNATURE is summarized in Table 12-13.

O-SIGNATURE shall be automatically repeated (AR mode).



**Table 12-13/G.993.1 – Description of message O-SIGNATURE**

Field content	Field or macro-field type
Message descriptor	Message code (see Table 12-12)
Used band in downstream	Bands descriptor (see Table 12-14)
Used band in upstream	Bands descriptor
RFI bands	Band descriptor
Transmit PSD in downstream	PSD descriptor (see Table 12-15)
Receive or transmit PSD mask selector for PBO	1 byte
Maximal transmit PSD in upstream	PSD descriptor
Reference PSD	PSD descriptor
Length of the transmit window, $\beta$	1 byte

Every SOC message shall start with a field that contains a unique code describing that message. This allows fast and easy recognition of SOC messages. See Table 12-12 for the complete list of codes.

Fields two through four contain a "bands descriptor". The first octet of these fields shall contain the number of bands being described. After the first octet, groups of 3 consecutive octets shall describe each band. The first 12 bits (0-11) shall contain the index of the tone at the lower edge of the band. The last 12 bits (12-23) shall contain the index of the tone at the upper edge of the band. The starting and ending tones shall be included in the band. For example, a field value 0x400200 means that all tones from 0x200 = 512 to 0x400 = 1024 are used, including tones 512 and 1024.

The structure of a bands descriptor is shown in Table 12-14.

**Table 12-14/G.993.1 – Bands descriptor**

Octet	Content of field
1	Number of bands to be described
2-4	Bits 0-11: Start tone index of band 1 Bits 12-23: Ending tone index of band 1
5-7 (if applicable)	Bits 0-11: Start tone index of band 2 Bits 12-23: Ending tone index of band 2
etc.	etc.

Fields five, seven and eight contain a "PSD descriptor". The first octet of this field shall contain the number of tones being specified. After the first octet, groups of 3 consecutive octets shall describe the PSD at a certain tone index. The first 12 bits (0-11) shall contain the index of the tone being described. The last 12 bits (12-23) shall contain the PSD level. The PSD level shall be an integer multiple of 0.5 dB with an offset of -140 dBm/Hz. For example, a field value of 0x0A0400 means a PSD of  $0x0A0 \times 0.5 - 140 = -60$  dBm/Hz on tone index 0x400 = 1024. The PSD level of intermediate unspecified tones shall be obtained using a linear interpolation between the given PSD points (in dBm/Hz) with the frequency axis on a linear scale. The PSD descriptor is described in Table 12-15. The PSD descriptor shall contain the PSD template.

**Table 12-15/G.993.1 – PSD descriptor**

Octet	Content of field
1	Number of tones being described
2-4	Bits 0-11: Index of first tone being described Bits 12-23: PSD level in steps of 0.5 dB with an offset of -140 dBm/Hz
5-7 (if applicable)	Bits 0-11: Index of second tone being described Bits 12-23: PSD level in steps of 0.5 dB with an offset of -140 dBm/Hz
etc.	etc.

The sixth field of O-SIGNATURE shall be a flag indicating whether the transmit PSD at the VTU-R should be calculated from the maximal receive PSD (field eight) or not. If this field has the value 0xFF, the upstream transmit PSD shall be calculated using the reference PSD given in field eight (see 9.2.4). If this field has the value 0x00, the transmit PSD at the VTU-R shall be determined from the maximal upstream PSD only (field seven). The last field in the O-SIGNATURE message shall contain the length of the transmit window, counted in samples at the sampling rate corresponding to the negotiated value of  $N$ . This sampling rate is given by  $2N_{SC} \Delta f = N \Delta f$  (i.e., 2 times the Nyquist frequency of an  $N_{SC}$ -tone multi-carrier signal).

#### **12.4.4.2.1.2 O-UPDATEn**

This message shall be used to instruct the VTU-R to tune its transmit PSD to optimize the power back-off and allows the VTU-O to optimize the timing advance. O-UPDATEn shall be repeated only at the request of the VTU-R (see R-ACKn (12.4.4.3.1.2), R-NACKn (12.4.4.3.1.3)). The structure of O-UPDATEn is shown in Table 12-16.

**Table 12-16/G.993.1 – Description of message O-UPDATEn**

Field content	Field or macro-field type
Message descriptor	Message code (see Table 12-12)
Gain update	Update descriptor (see Table 12-17)
Timing advance correction	2 bytes

This message shall contain a macro-field, called "Update descriptor". The first byte shall contain the number of tones specified in this field. After the first octet, groups of 3 consecutive octets shall describe the gain to be applied at a given frequency. The first 12 bits shall contain the gain level, the next 12 bits the tone index. The gain level is the amplification applied on one tone. It shall be specified in 2's complement format in steps of 0.25 dB. For example, a field value of 0x030400 means a PSD amplification of  $0x030 \times 0.25 = 12$  dB on the tone index  $0x400 = 1024$ . The gain on unspecified tones shall be derived by linear interpolation between tones specified using a dB gain scale and a linear frequency scale.

The update descriptor is shown in Table 12-17.



**Table 12-17/G.993.1 – Update descriptor**

Octet	Content of field
1	Number of tones to be described
2-4	Bits 0-11: Index of first tone being described Bits 12-23: Gain level adjustment in 2's complement in steps of 0.25 dB
5-7 (if applicable)	Bits 0-11: Index of second tone being described Bits 12-23: Gain level adjustment in 2's complement in steps of 0.25 dB
etc.	etc.

The last field of O-UPDATEn shall define the timing advance correction in samples at the sampling rate corresponding to the negotiated value of  $N$  ( $2N_{SC} \Delta f$ ; see 12.4.4.2.1.1). The value shall be encoded in a 16-bit field using 2's complement format. Positive values shall indicate that the transmitted symbol will be advanced more with respect to the received symbol (see Figure 9-3).

#### **12.4.4.2.1.3 O-MSG1**

This message shall contain the final length of the  $CE$  expressed in samples at the sampling frequency corresponding to the negotiated value of  $N$ . The message is described in Table 12-18. O-MSG1 shall be sent only once and shall only be repeated if the VTU-R sends a repeat request.

The final  $CE$  length shall be applied from the beginning of channel analysis phase.

**Table 12-18/G.993.1 – Description of message O-MSG1**

Field content	Field or macro-field type
Message descriptor	Message code (see Table 12-12)
Final length of $CE$	2 bytes

#### **12.4.4.2.2 Symbol types transmitted by VTU-O**

During the entire training phase, the VTU-O shall transmit the symbol O-P-TRAINING. To signal the end of the training phase, O-P-SYNCHRO1 shall be transmitted.

##### **12.4.4.2.2.1 O-P-TRAINING**

O-P-TRAINING is a wideband signal that allows the VTU-R to synchronize and to measure the attenuation over the channel. It shall be made of all the allowed downstream tones modulated in 4QAM, using the constellation encoder described in 9.2.5. The symbol length is  $N+CE$  samples.  $N$  and  $CE$  shall be as specified during the initial G.994.1 protocol. Windowing shall be applied at the transmitter and the overall window length shall be equal to  $\beta$ . The transmit PSD is defined by the network management. O-P-TRAINING shall carry one byte of information per DMT symbol. The information mapping is summarized in Table 12-19.



**Table 12-19/G.993.1 – O-P-TRAINING bit mapping**

Tone index	Constellation point
Even	00
1, 11, 21, ..., $10n + 1$ , ...	SOC message bits 0 & 1
3, 13, 23, ..., $10n + 3$ , ...	SOC message bits 2 & 3
5, 15, 25, ..., $10n + 5$ , ...	SOC message bits 4 & 5
7, 17, 27, ..., $10n + 7$ , ...	SOC message bits 6 & 7
9, 19, 29, ..., $10n + 9$ , ...	00

The selected constellation points shall be pseudo-randomly rotated by  $0$ ,  $\pi/2$ ,  $\pi$  or  $3\pi/2$  depending on the value of a 2-bit pseudo-random number. The DC component shall not be rotated. The rotation is equivalent to the following transformation of the  $(X, Y)$  coordinates, where  $X$  and  $Y$  are the coordinates before scrambling:

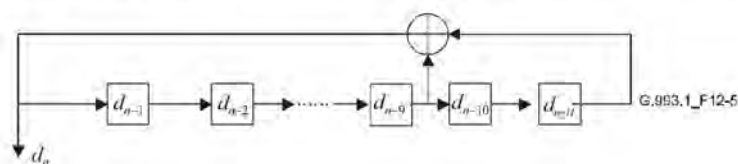
**Table 12-20/G.993.1 – Pseudo-random transformation**

$d_{2n}$ , $d_{2n+1}$	Angle of rotation	Final coordinates
0 0	0	$(X, Y)$
0 1	$\pi/2$	$(-Y, X)$
1 1	$\pi$	$(-X, -Y)$
1 0	$3\pi/2$	$(Y, -X)$

The 2-bit pseudo-random number shall be the output of a pseudo-random bit generator defined by the following equation:

$$d_n = d_{n-9} \oplus d_{n-11}$$

Two bits of the scrambler shall be mapped onto each tone, including DC. The two bits corresponding to DC shall be overwritten with 00. The bit generator is illustrated in Figure 12-5.

**Figure 12-5/G.993.1 – Bit generator**

For a VDSL system that uses  $N$  tones,  $2N$  bits shall be generated by the scrambler every DMT-symbol ( $b_0 b_1 b_2 \dots b_{2N-2} b_{2N-1}$ ). These  $2N$  bits shall be generated in every transmission direction. The first two bits ( $b_0 b_1$ ) shall correspond to tone 0, the next two bits ( $b_2 b_3$ ) to tone 1, .... In general, bits ( $b_{2j} b_{2j+1}$ ) shall correspond to tone  $j$ . Tones that are not used for transmission will not effectively use the bits, but it is still required to generate  $2N$  bits.

Initially, all the registers of the bit generator shall be set to one. During the training phase, the scrambler shall be reset at the start of every symbol (meaning that all registers are reset to one) and therefore the same  $2N$  bits will be used every symbol. This means that each tone always has the same two bits assigned to it for successive DMT symbols.

In the channel analysis state (see 12.4.6), the scrambler shall not be reset, but keeps running from one symbol to the next. It is required that the sequence be random in time for one single tone. This

means that there should be no correlation between the two bits that are mapped on tone  $j$  during symbol  $m$  and the two bits that are mapped on the same tone during symbol  $m+1$ . In order to guarantee this<sup>1</sup> for all allowed values of  $N$ , a number of output bits from the quadrant scrambler shall be skipped when going from symbol  $m$  to symbol  $m+1$ . The number of skipped bits shall be equal to 4.

In practice this means that the quadrant scrambler generates  $2N$  bits which are allocated to symbol  $m$ . The next four bits generated by the quadrant scrambler are not used. The next  $2N$  bits from the quadrant scrambler are then allocated to symbol  $m+1$ .

#### **12.4.4.2.2.2 O-P-SYNCHRO1**

O-P-SYNCHRO1 is a wideband signal that allows the VTU-O and the VTU-R to simultaneously step into the channel analysis and exchange state. It shall use all the allowed downstream tones modulated in 4QAM. The symbol length shall be  $N+CE$  samples.  $N$  and  $CE$  shall be set to the values specified in ITU-T Rec. G.994.1. Windowing shall be applied at the transmitter and the overall window length  $\beta$  shall be set to the value specified in O-SIGNATURE (see 12.4.4.2.1.1). The PSD mask is defined by the network management. The overall duration of O-P-SYNCHRO1 shall be 15 DMT symbols. The value 11 shall be mapped on all the allowed downstream tones for the 5 first and the 5 last DMT symbols. The value 00 shall be mapped on the allowed downstream tones for the 5 remaining DMT symbols. The selected constellation points shall be pseudo-randomly rotated by  $0$ ,  $\pi/2$ ,  $\pi$  or  $3\pi/2$  depending on the 2-bit random number provided by the pseudo-random bit generator defined in 12.4.4.2.2.1.

The scrambler shall be reset every symbol.

(See Notes in 12.4.4.1.)

### **12.4.4.3 Messages and symbols transmitted by VTU-R during training state**

#### **12.4.4.3.1 SOC messages**

During the training state, the VTU-R will send the SOC messages R-MSG1, R-ACKn and R-NACKn as well as the idle message R-IDLE. The way these messages are modulated on the transmit symbol is described in 12.4.4.3.2.

##### **12.4.4.3.1.1 R-MSG1**

This message shall contain the description of the transmit PSD of the VTU-R. This PSD shall be encoded in one macro-field "PSD descriptor" as described in Table 12-15. The PSD level on unspecified tones shall be obtained by using a linear interpolation between the PSD in dBm/Hz, using a linear frequency scale.

The initial estimate for the transmit PSD shall be obtained differently depending on the value of the selector byte in O-SIGNATURE. If this byte indicates that the modem should use the reference PSD, it shall be computed by dividing the reference PSD by the estimate of the upstream channel insertion loss. The transmit PSD shall however always be bounded by the upstream PSD mask. Otherwise, the transmit PSD shall just be the upstream PSD mask transferred from the VTU-O to the VTU-R in O-SIGNATURE.

R-MSG1 shall also indicate whether the optional echo canceller state should be entered or bypassed.

R-MSG1 shall be repeated automatically. The transmission shall be stopped after detection of O-UPDATE1.

<sup>1</sup> An alternative solution would be to make the scrambler adaptive, depending on the (I)FFT size. This approach is currently being investigated in ITU-T Rec. G.992.1.



**Table 12-21/G.993.1 – Description of R-MSG1**

<b>Field content</b>	<b>Field or macro-field type</b>
Message descriptor	Message code (see Table 12-12)
Transmit PSD in upstream	PSD descriptor (see Table 12-15)
Echo canceller training flag	1 byte (0x00: No echo canceller training; 0xFF: Echo canceller training required)

**12.4.4.3.1.2 R-ACK<sub>n</sub>**

This message is an acknowledgement of the O-UPDATEn message. It shall be sent only once, unless the VTU-O asks for a retransmission. The message shall contain the byte 0x00. Five symbols after sending this message, the VTU-R shall change its symbol type from R-P-TRAINING<sub>n</sub> to R-P-TRAINING<sub>n+1</sub>. On reception of this message, the VTU-O could decide to ask for a new update by sending O-UPDATEn+1 or to end the iterative VTU-R PSD optimization by sending O-MSG1.

If the VTU-R receives a REPEAT\_REQUEST for this message, it shall take the following actions to repeat the message:

- Return to the symbol type R-P-TRAINING<sub>n</sub>;
- Send back R-ACK<sub>n</sub>;
- Return to the symbol type R-P-TRAINING<sub>n+1</sub>.

**12.4.4.3.1.3 R-NACK<sub>n</sub>**

This message shall be sent when the VTU-R is unable to apply the update encoded in O-UPDATEn. It shall be sent only once, unless the VTU-O asks for a retransmission. The message shall contain one byte 0xFF. Upon reception of this message, the VTU-O can decide to continue the initialization by sending either O-UPDATEn or O-MSG1 or to abort the initialization.

**12.4.4.3.2 Symbol types transmitted by the VTU-R**

During the training phase, the VTU-R shall transmit the various R-P-TRAINING<sub>n</sub> symbols. These will differ in their PSD level and in the timing advance that is applied to the symbols. To trigger the transition from training phase to channel analysis and exchange (in the upstream direction), the signal R-P-SYNCHRO1 shall be transmitted.

**12.4.4.3.2.1 R-P-TRAINING<sub>n</sub>**

R-P-TRAINING<sub>n</sub> is a wideband signal that allows the VTU-O to optimize the VTU-R timing advance (TA) and the VTU-R transmit PSD in order to be compliant with the power back-off requirement. R-P-TRAINING shall be made of all the allowed upstream tones modulated in 4QAM. The symbol length shall be  $N+CE$  samples.  $N$  and  $CE$  shall have the values specified during the initial G.994.1 protocol. Windowing shall be applied at the transmitter with the window length  $\beta$  as specified in O-SIGNATURE. The PSD mask shall be chosen to be compliant with the power back-off requirement defined in O-SIGNATURE (see 12.4.4.2.1.1).

Afterward, the PSD mask shall be updated on the basis of the instructions transmitted by the VTU-O by means of O-UPDATEn. R-P-TRAINING<sub>n</sub> will essentially be identical to R-P-TRAINING<sub>1</sub>, apart from the PSD level and timing advance.

Timing advance shall be applied. At the first iteration (R-P-TRAINING<sub>1</sub>), the timing advance shall be set to a value corresponding to the default loop length (1.5 km or 7.5  $\mu$ s). Afterward, the timing advance shall be updated on the basis of the instruction transmitted by the VTU-O by means of

O-UPDATEn. R-P-TRAINING shall carry one byte of information per DMT symbol. The information mapping is summarized in Table 12-22.

**Table 12-22/G.993.1 – R-P-TRAINING bit mapping**

<b>Tone index</b>	<b>Constellation point</b>
Even	00
1, 11, 21, ..., $10n + 1$ , ...	SOC message bits 0 & 1
3, 13, 23, ..., $10n + 3$ , ...	SOC message bits 2 & 3
5, 15, 25, ..., $10n + 5$ , ...	SOC message bits 4 & 5
7, 17, 27, ..., $10n + 7$ , ...	SOC message bits 6 & 7
9, 19, 29, ..., $10n + 9$ , ...	00

The point 00 corresponds to a point in the first quadrant, in accordance with a 4QAM constellation.

The selected constellation points shall be pseudo-randomly rotated by  $0$ ,  $\pi/2$ ,  $\pi$  or  $3\pi/2$  depending on the value of a 2-bit pseudo-random number provided by the pseudo-random generator described in 12.4.4.2.2.1. The DC component shall not be rotated. The scrambler shall be reset at the start of every symbol.

#### **12.4.4.3.2.2 R-P-SYNCHRO1**

R-P-SYNCHRO1 is a wideband signal that allows the VTU-O and the VTU-R to simultaneously step into the channel analysis and exchange state. It shall use all of the allowed upstream tones modulated in 4QAM. The symbol length shall be  $N+CE$  samples.  $N$  and  $CE$  shall have the values specified during the initial G.994.1 protocol. Windowing shall be applied at the transmitter and the overall window length  $\beta$  shall be set to the value specified in O-SIGNATURE. The transmit PSD mask shall meet the power back-off requirements. The timing advance shall be applied and shall correspond to the loop length (the final value shall be determined by the VTU-O). The overall duration of R-P-SYNCHRO1 shall be 15 DMT symbols. Value 11 shall be mapped on all the allowed upstream tones for the 5 first DMT symbols and the 5 last DMT symbols. Value 00 shall be mapped on all the allowed upstream tones for the 5 remaining DMT symbols. The selected constellation points shall be pseudo-randomly rotated by  $0$ ,  $\pi/2$ ,  $\pi$ ,  $3\pi/2$  depending on the 2-bit random number generated by a pseudo-random bit generator defined in 12.4.4.2.2.1.

The scrambler shall be reset at the start of every symbol.

(See Notes in 12.4.4.1.)

#### **12.4.5 Echo canceller training state (optional)**

The echo canceller state is optional in the sense that it will be skipped when modems do not need to train an echo canceller. Any modem that requires this state shall be able to demand that it is included in the initialization sequence.

Some modems may use an (analog) echo canceller that will have to be trained at some point during the initialization sequence. During the training of an echo canceller, the other side shall be completely quiet.

Such a silent period exists for the VTU-O at the beginning of the training state. Here, the VTU-R will be quiet until it has decoded O-SIGNATURE correctly. This period could be used by the VTU-O to train its echo canceller. It could even make the available period longer by delaying the transmission of O-SIGNATURE and sending IDLE messages instead (see Figure 12-4).

The VTU-R does not have a convenient echo canceller training state however. Therefore, the modems can follow two different paths after the PSD training. It shall be signalled in R-MSG1



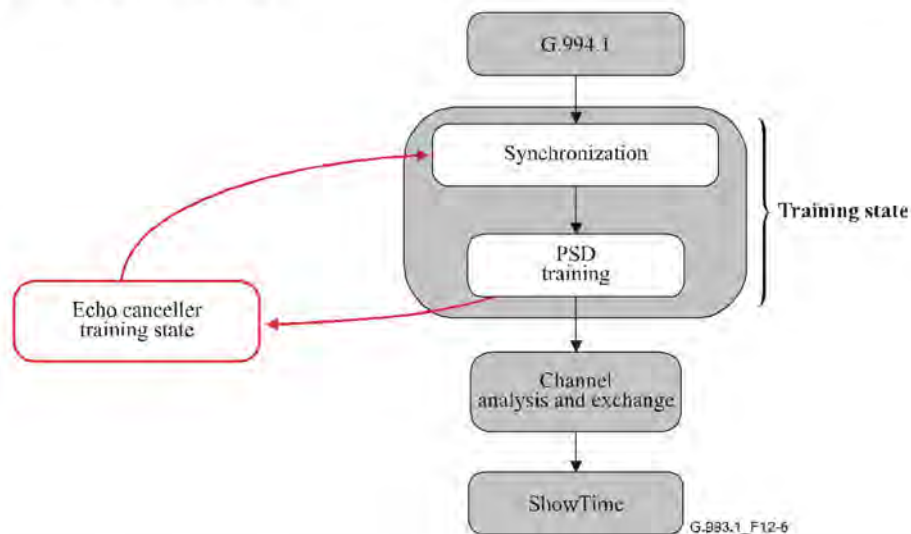
whether an echo canceller training state is required for the VTU-R. If so, both modems shall go to the echo canceller training state at the end of the PSD training state.

In the echo canceller training state, the VTU-O shall go completely silent after transmission of O-MSG1 and shall perform no operations, other than listening to the signal on the line. After reception of O-MSG1, the VTU-R shall keep transmitting the same signal as during the last phase of the training state.

In this state, the VTU-R shall train its echo canceller with a proprietary algorithm. After completion of this task, the VTU-R shall go completely silent. This transition (no power on the line) shall be detected by the VTU-O, which shall react by returning to the beginning of the training state (synchronization).

NOTE – The situation is now identical to that at the beginning of initialization: the VTU-R is quiet and the VTU-O starts the communication.

After performing an echo canceller training, the content of R-MSG1 shall be changed such that at the second pass through the PSD training state, the sequence will continue with the channel analysis state and not perform another echo canceller training. At the second pass, the VTU-R already knows its correct transmit PSD, so the training phase will automatically be shortened. There is no need to explicitly bypass any stages.



**Figure 12-6/G.993.1 – Position of (optional) echo canceller training state in the initialization procedure**

### 12.4.6 Channel analysis and exchange

Figure 12-7 gives an overview of the sequence of SOC messages and symbol types during the channel analysis and exchange state.

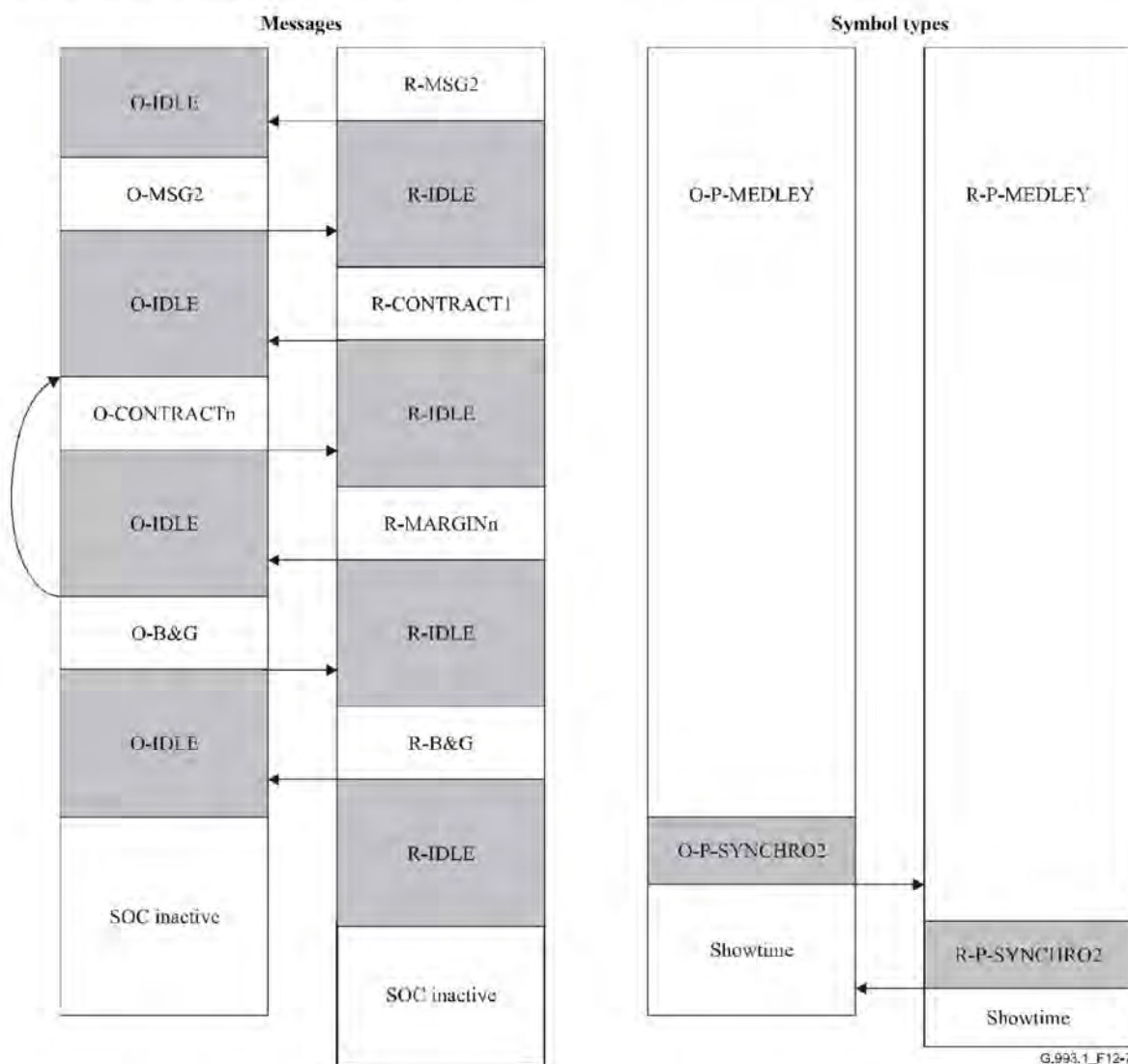


Figure 12-7/G.993.1 – Timeline of the channel analysis and exchange phase

#### 12.4.6.1 Sequence of messages and symbols during channel analysis and exchange state

The sequence of SOC messages and symbols is depicted in Figure 12-7. Upon entering the channel analysis and exchange state, the VTU-R shall transmit symbol type R-P-MEDLEY, while the VTU-O shall send O-P-MEDLEY. The VTU-R shall send the message R-MSG2 over the SOC channel to transfer information about its bit allocation capabilities and several other features. After receiving this message, the VTU-O shall do the same by sending the SOC message O-MSG2, containing the capabilities of the VTU-O.

After receiving O-MSG2, the VTU-R shall send the SOC message R-CONTRACT1, which contains the proposed contract in downstream.



Following this, the VTU-O and VTU-R shall enter an iterative procedure to agree on a contract for the transmission in upstream and downstream. At the  $n$ th iteration, the VTU-O shall send O-CONTRACT $n$ . The VTU-R shall reply with R-MARGIN $n$ .

To end the contract negotiations, the VTU-O shall transmit the message O-B&G. After receiving this message, the VTU-R shall send the message R-B&G. After receiving R-B&G, the VTU-O shall initiate the transition to ShowTime by sending the symbol O-P-SYNCHRO2, which allows a simultaneous transition at both sides in the downstream direction. The VTU-R shall reply by sending the message R-P-SYNCHRO2, which allows a simultaneous transition in the upstream direction.

#### 12.4.6.2 Messages and symbols transmitted by VTU-O

##### 12.4.6.2.1 SOC messages

During the channel analysis and exchange phase, the VTU-O will send the SOC messages O-MSG2, O-CONTRACT $n$  and O-B&G as well as the idle message O-IDLE.

The way these messages are modulated on the transmit symbol is described in 12.4.6.2.2. The sequence in which the messages are sent is illustrated in Figure 12-7 and explained in more detail in 12.4.6.1.

During this state, all messages shall be sent in RQ-mode (see 12.4.2.1).

##### 12.4.6.2.1.1 O-MSG2

This message contains information about the capability of VTU-O for contract negotiation. The content of O-MSG2 shall be as shown in Table 12-23.

**Table 12-23/G.993.1 – Description of O-MSG2**

Field content	Field or macro-field type	Remark
Message descriptor	1 byte	See Table 12-12.
Minimal SNR margin	1 byte	In units of 0.5 dB
Maximal constellation size in downstream ( $B_{max,d}$ )	1 byte	Maximum number of bits per tone
RS setting supported by VTU-O	1 byte	0x00: Only mandatory settings 0xFF: All settings
Interleaver settings supported by the VTU-O	1 byte	0x00: Only mandatory settings 0xFF: All settings 0xNN NN = Number of additional (i.e., non-mandatory) settings in hexadecimal (NN $\neq$ 0x00 and NN $\neq$ 0xFF)
Detailed interleaver setting description	0 byte if NN = 0x00 or NN = 0xFF, 4xNN otherwise	Interleaver descriptor (see Table 12-24)
Maximal power in downstream	1 byte (unsigned)	In units of 0.25 dBm
Maximum interleaver delay	1 byte	In ms by steps of 0.5 ms (Note 1)
Maximum number of EOC bytes per frame in downstream	1 byte	Number of EOC bytes per frame
Maximum number of VOC bytes per frame in downstream	1 byte	Number of VOC bytes per frame

**Table 12-23/G.993.1 – Description of O-MSG2**

Field content	Field or macro-field type	Remark
Support of express bit swapping	1 byte	0x00: Not supported 0xFF: Supported
$j_{\max}$	1 byte	Maximum value of $j_{\max}$ supported by the VTU-O (Note 2)
NOTE 1 – This field can be set to 0 in order to emulate the fast channel. This field is used for the creation of R-CONTRACT1 even if dual latency is used at the end.		
NOTE 2 – Specification of $j_{\max} = k$ means that all values 0, 1, ..., $k$ are supported.		

$j_{\max}$  is defined in 12.4.6.2.1.3.

The structure of the interleaver descriptor shall be as given in Table 12-24.  $I$ ,  $q$  and  $M$  are the interleaver parameters (see 8.4.2).

**Table 12-24/G.993.1 – Interleaver descriptor**

Field	Field or macro-field type
$I$	1 byte
$q$	1 byte
$M_{\min}$	1 byte
$M_{\max}$	1 byte
NOTE – The four fields are repeated for each interleaver setting.	

#### 12.4.6.2.1.2 O-CONTRACTn

This message shall contain a proposal of an upstream and downstream contract and the EOC and VOC capacity, based on the EOC and VOC capabilities of both modems (exchanged during O-MSG1 and R-MSG1). The downstream contract shall be based on the information carried by R-CONTRACT1. Ideally, the downstream contract is the same as the one proposed in R-CONTRACT1. Table 12-25 describes O-CONTRACTn.

**Table 12-25/G.993.1 – Description of O-CONTRACTn**

Field	Field or macro-field type
Message descriptor	Message code (see Table 12-12)
Downstream contract	Contract descriptor (see Table 12-26)
Upstream contract	Contract descriptor
EOC capacity (number of EOC bytes per frame)	1 byte
VOC capacity (value of $V$ ; see 8.5.5)	1 byte

Both upstream and downstream contracts shall be encoded in a macro-field called "Contract descriptor". This macro-field contains all the necessary data for the setting of the framing. The contract descriptor shall be as described in Table 12-26. It shall specify the rates in upstream and downstream and the encoder settings.



**Table 12-26/G.993.1 – Contract descriptor**

Field	Field or macro-field type	Remark
Rate in fast channel	2 bytes	In multiples of 64 kbit/s
RS setting in fast channel	2 bytes	B15 → B8: RS overhead B7 → B0: RS codeword length
Rate in slow channel	2 bytes	In multiples of 64 kbit/s
RS setting in slow channel	2 bytes	B15 → B8: RS overhead B7 → B0: RS codeword length
Interleaver setting	2 bytes	B15 → B8: <i>M</i> (Note) B7 → B0: <i>I</i>
NOTE – <i>I</i> must be a divider of the RS codeword length (in the slow channel).		

**12.4.6.2.1.3 O-B&G**

O-B&G shall signal the end of the contract negotiation and shall be used to transmit to the VTU-R the bits and the gains information that are to be used in the upstream direction.  $b_i$  shall indicate the number of bits to be coded by the VTU-R onto the carrier  $i$ ;  $g_i$  shall indicate the scale factor, relative to the gain that was used for that carrier during the transmission of R-P-MEDLEY, that shall be applied onto the carrier  $i$ .

The  $b_i$ s and  $g_i$ s shall only be defined for those tones that are used during the transmission of R-P-MEDLEY (i.e., the upstream tones indicated in O-SIGNATURE). Because no bits or energy will be transmitted at the other frequencies (at least in the upstream direction), the corresponding  $b_i$ s and  $g_i$ s shall all be presumed to be equal to zero and shall not be transmitted.

The  $b_i$ s and  $g_i$ s shall be transmitted in ascending order (i.e., from lowest to highest tone). In case all  $b_i$ s above a certain tone are zero, the remaining zero values do not have to be transmitted. The VTU-R shall assume that any missing  $b_i$ s and  $g_i$ s after the last received value correspond to tones that carry no bits.

Each  $b_i$  shall be represented as an unsigned 4-bit integer. Valid  $b_i$ s shall lie in the range of zero to  $B_{\max\_u}$ , the maximum number of bits that the VTU-R is prepared to modulate onto any subcarrier.

Each  $g_i$  shall be represented as an unsigned 12-bit fixed-point quantity, with the binary point assumed just to the right of the third most significant bit. For example, a  $g_i$  with binary representation (most significant bit listed first) 001.01000000<sub>2</sub> would instruct the VTU-R to scale the constellation for carrier  $i$ , by a gain of 1.25, so that the power in that carrier shall be 1.94 dB higher than it was during R-P-MEDLEY.

The whole spectrum shall be split up into groups of adjacent tones such that the number of bits allocated to the carriers of a group is constant. The length of all the groups of carriers need not be constant but it cannot exceed 255 carriers. The scale factor  $g_i$  for each carrier within a group is defined by a polynomial interpolation. This polynomial is specified by means of the values taken on at  $(j_{\max} + 1)$  defined tones, where  $j_{\max}$  is the order of the polynomial. The  $(j_{\max} + 1)$  tones are chosen to be (almost) equidistant (see below). In the case of a group of carriers  $[x_n, x_{n+1}]$ , where  $x_n$  and  $x_{n+1}$  are the carrier indexes of the lowest and the highest tones respectively of the  $n$ -th group of carriers, the  $(j_{\max} + 1)$  positions  $X_{nj}$  of the tones that will be used in the interpolation are defined as:

$$X_{nj} = x_n + \left\lfloor \frac{j(x_{n+1} - x_n)}{j_{\max}} \right\rfloor \text{ for } j = 0 \dots j_{\max}$$

$j_{\max}$  shall be chosen by the VTU-O based on the values supported by the VTU-R as specified in R-MSG2.

The O-B&G message is defined in Table 12-27.

**Table 12-27/G.993.1 – Description of message O-B&G**

Field content	Field or macro-field type
Message descriptor	Message code (See Table 12-12.)
$j_{\max}$	1 byte
$b_{\mu}$ s and $g_i$ information	B&G descriptor (See Tables 12-28 to 12-30.)

**Table 12-28/G.993.1 – B&G descriptor  $j_{\max} = 0$**

Byte	Content of field
$2n + 1 \rightarrow 2n + 2$	Specification of tone $n + 1$ for $n = 0$ to $N_{SC} - 2$ (Note) Bits 0-3: Number of bits $b_n$ Bits 4-15: Scale gain $g_n$
NOTE – If tone $n$ is not used in the upstream direction, specification is not transmitted.	

**Table 12-29/G.993.1 – B&G descriptor  $j_{\max} > 0$  and odd**

Byte	Content of field
$1 \rightarrow 2$	$N_{gr}$ (Number of groups of tones)
$3 + n \times (1.5 j_{\max} + 3.5) \rightarrow 3 + (n + 1) \times (1.5 j_{\max} + 3.5) - 1$	Specification of tones in group $n + 1$ for $n = 0$ to $N_{gr} - 1$ Bits 0-3: Number of bits Bits 4-15: Number of carriers of group $n + 1$ Bits $16 + 12j \rightarrow 27 + 12j$ : $g_{X_{nj}}$ for tones $X_{nj} j = 0$ to $j_{\max}$

**Table 12-30/G.993.1 – B&G descriptor  $j_{\max} > 0$  and even**

Byte	Content of field
$1 \rightarrow 2$	$N_{gr}$ (Number of group of tones)
$3 + n \times (1.5 j_{\max} + 3) \rightarrow 3 + (n + 1) \times (1.5 j_{\max} + 3) - 1$	Specification of tones in group $n + 1$ for $n = 0$ to $N_{gr} - 1$ Bits 0-3: Number of bits Bits 4-11: Number of carriers of group $n + 1$ Bits $12 + 12j \rightarrow 23 + 12j$ : $g_{X_{nj}}$ for tones $X_{nj} j = 0$ to $j_{\max}$

#### 12.4.6.2.2 Symbol types transmitted by VTU-O

##### 12.4.6.2.2.1 O-P-MEDLEY

O-P-MEDLEY is a wideband signal used for estimation at the VTU-R of the downstream SNR. O-P-MEDLEY shall be made of all the allowed downstream tones modulated in 4QAM. The symbol length shall be  $N + CE$  samples.  $N$  shall be set to the value specified in ITU-T Rec. G.994.1 and  $CE$  shall be set to the value specified in O-MSG1 (see 12.4.4.2.1.3). The change in  $CE$  shall be made after transmission of O-P-SYNCHRO2. Any change in  $CE$  shall be made at the beginning of the DMT symbol (i.e., by changing the number of samples in  $L_{CP}$ ; see 9.2.2). Windowing shall be applied at the transmitter and the overall window length  $\beta$  shall be equal to the value specified in O-SIGNATURE (see 12.4.4.2.1.1). The PSD mask is defined by the network management.



O-P-MEDLEY shall carry 2 bytes of information ( $b_{15} b_{14} \dots b_0$ ) per DMT symbol. The mapping shall be as described in Table 12-31.

**Table 12-31/G.993.1 – O-P-MEDLEY bit mapping**

Tone index	Constellation point
5, 10, 15, ..., $5n$ , ...	00
1, 11, 21, ..., $10n + 1$ , ...	SOC message bits 0 & 1
2, 12, 22, ..., $10n + 2$ , ...	SOC message bits 2 & 3
3, 13, 23, ..., $10n + 3$ , ...	SOC message bits 4 & 5
4, 14, 24, ..., $10n + 4$ , ...	SOC message bits 6 & 7
6, 16, 26, ..., $10n + 6$ , ...	SOC message bits 8 & 9
7, 17, 27, ..., $10n + 7$ , ...	SOC message bits 10 & 11
8, 18, 28, ..., $10n + 8$ , ...	SOC message bits 12 & 13
9, 19, 29, ..., $10n + 9$ , ...	SOC message bits 14 & 15

The selected constellation points shall be pseudo-randomly rotated by  $0$ ,  $\pi/2$ ,  $\pi$  or  $3\pi/2$  depending on the value of a 2-bit random number provided by the pseudo-random bit generator defined in 12.4.4.2.2.1. Two bits shall be mapped onto each tone including DC. The pseudo-random bit sequence shall continue from one symbol to the next one. The scrambler shall be reset only when the VTU-O enters the channel analysis and exchange state.

NOTE – Between any two consecutive DMT symbols, a number of bits of the random bit generator shall be skipped, as discussed in 12.4.4.2.2.1.

#### **12.4.6.2.2.2 O-P-SYNCHRO2**

O-P-SYNCHRO2 is a wideband signal that allows the VTU-O and the VTU-R to simultaneously step into the ShowTime state (in the downstream direction). It uses all the allowed downstream tones modulated in 4QAM. The symbol length shall be  $N+CE$  samples.  $N$  shall be set to the value specified in ITU-T Rec. G.994.1 and  $CE$  shall be set to the value specified in O-MSG1 (see 12.4.4.2.1.3). Windowing shall be applied at the transmitter and the overall window length  $\beta$  shall be set to the value specified in O-SIGNATURE (see 12.4.4.2.1.1). The PSD mask is defined by the network management. The overall duration of O-P-SYNCHRO2 shall be 15 DMT symbols. The value 11 shall be mapped on all the allowed downstream tones for the 5 first and the 5 last DMT symbols. The value 00 shall be mapped on the allowed downstream tones for the 5 remaining DMT symbols. The selected constellation points shall be pseudo-randomly rotated by  $0$ ,  $\pi/2$ ,  $\pi$ ,  $3\pi/2$  depending on the 2-bit random sequence provided by the pseudo-random bit generator defined in 12.4.4.2.2.1. The pseudo-random bit sequence shall continue from symbol to the next one.

The scrambler shall be running free during the transmission of this O-P-SYNCHRO2.

In the downstream direction, the quadrant scrambler shall be disabled after the transmission of O-P-SYNCHRO2.

#### **12.4.6.3 Messages and symbols transmitted by VTU-R**

##### **12.4.6.3.1 SOC messages**

During the channel analysis and exchange phase, the VTU-R will send the SOC messages R-MSG2, R-CONTRACT<sub>n</sub>, R-MARGIN<sub>n</sub> and R-B&G as well as the idle message R-IDLE. The way these messages are modulated on the transmit symbol is described in 12.4.6.3.2.

**12.4.6.3.1.1 R-MSG2**

This message contains information about the capabilities of the VTU-R for bit allocation. The content of R-MSG2 shall be as specified in Table 12-32.

**Table 12-32/G.993.1 – Description of R-MSG2**

Field	Field or macro-field type	Remark
Message descriptor	1 byte	See Table 12-12.
Maximal constellation size in upstream ( $B_{\max, u}$ )	1 byte	Maximum number of bits per tone
RS setting supported by VTU-R	1 byte	0: Only mandatory settings 1: All settings
Interleaver settings supported by the VTU-R	1 byte	0x00: Only mandatory settings 0xFF: All settings 0xNN NN = Number of additional (i.e., non-mandatory) settings in hexadecimal (NN $\neq$ 0x00 and NN $\neq$ 0xFF)
Detailed interleaver setting description	0 byte if NN = 0x00 or NN = 0xFF; 4xNN otherwise	Interleaver descriptor (See Table 12-24.)
Maximal power transmitted	1 byte (unsigned)	In dBm by steps of 0.25 dBm
Maximal interleaver memory	3 bytes	In bytes (Note 1)
Maximum number of EOC bytes per frame in upstream	1 byte	Number of EOC bytes per frame
Maximum number of VOC bytes per frame in upstream	1 byte	Number of VOC bytes per frame
Support of express bit swapping	1 byte	0x00: Not supported 0xFF: Supported
$j_{\max}$	1 byte	Specify maximum value of $j_{\max}$ supported by the VTU-R (Note 2)
NOTE 1 – The interleaver memory is computed as $M \times I \times (I - 1)$ .		
NOTE 2 – Specification of $j_{\max} = k$ means that all values from 0, 1, ..., $k$ are supported.		

**12.4.6.3.1.2 R-CONTRACT1**

This message shall contain the proposed downstream contract based on the maximal number of bits in the slow channel based upon the restrictions specified in O-MSG2 (i.e., as if only the slow channel will be used). The contract shall be encoded in a "Contract descriptor" macro-field (see Table 12-26) with all fields related to the fast channel set to 0x00.

**12.4.6.3.1.3 R-MARGINn**

This message shall contain the SNR margin (i.e., the minimal SNR margin over all tones) computed by the VTU-R for the downstream contract proposed in O-CONTRACTn. Upon reception of R-MARGINn, the VTU-O can decide to choose this contract by sending O-B&G or to propose a new contract by sending O-CONTRACTn. The fields of R-MARGINn are described in Table 12-33.



**Table 12-33/G.993.1 – Description of R-MARGINn**

Field	Field or macro-field type	Remark
Message descriptor	1 byte	See Table 12-12.
SNR margin	1 byte	In dB by steps of 0.5 dB

**12.4.6.3.1.4 R-B&G**

R-B&G shall be used to transmit to the VTU-O the bits and the gains information that are to be used in the downstream direction.  $b_i$  indicates the number of bits to be coded by the VTU-O onto the carrier  $i$ ;  $g_i$  shall indicate the scale factor, relative to the gain that was used for that carrier during the transmission of O-P-MEDLEY, that shall be applied onto the carrier  $i$ .

The  $b_i$ s and  $g_i$ s shall only be defined for those tones that are used during the transmission of O-P-MEDLEY (i.e., the downstream tones indicated in O-SIGNATURE). Because no bits or energy will be transmitted at the other frequencies (at least in the downstream direction), the corresponding  $b_i$ s and  $g_i$ s shall all be presumed to be set to zero and shall not be transmitted.

The  $b_i$ s and  $g_i$ s shall be transmitted in ascending order (i.e., from lowest to highest tone). In case all  $b_i$ s above a certain tone are zero, the remaining zero values do not have to be transmitted. The VTU-O shall assume that any missing  $b_i$ s and  $g_i$ s after the last received value correspond to tones that carry no bits.

Each  $b_i$  shall be represented as an unsigned 4-bit integer, with valid  $b_i$ s lying in the range of zero to  $B_{\max\_d}$ , the maximum number of bits that the VTU-O is prepare to modulate onto any subcarrier.

Each  $g_i$  shall be represented as an unsigned 12-bit fixed-point quantity, with the binary point assumed just to the right of the third most significant bit. For example, a  $g_i$  with binary representation (most significant bit listed first)  $001.010000000_2$  would instruct the VTU-O to scale the constellation for carrier  $i$ , by a gain of 1.25, so that the power in that carrier shall be 1.94 dB higher than it was during O-P-MEDLEY.

If use of a dedicated pilot tone,  $k$ , is required, the VTU-R shall indicate this requirement to the VTU-O by sending the value "2" in the position of  $b_k$  in the bit table in R-B&G. In the gain table, it shall transmit a value of zero for the gain scaling of tone  $k$ . Receipt by the VTU-O of "2" in a bit table entry and zero in the corresponding gain scaling table entry indicates that this tone has been selected as a dedicated pilot and that it should be loaded with the 4QAM constellation point 00 during every symbol.

The whole spectrum shall be split up into groups of adjacent tones such that the number of bits allocated to the carriers of a group is constant. The length of all the groups of carriers need not be constant but it cannot exceed 255 carriers. The scale factor for each carrier within a group shall be defined by a polynomial interpolation. This polynomial shall be specified by means of the values taken on at  $(j_{\max} + 1)$  defined tones, where  $j_{\max}$  is the order of the polynomial. The  $(j_{\max} + 1)$  tones are chosen to be (almost) equidistant (see below). In the case of a group of carriers  $[x_n, x_{n+1}]$ , where  $x_n$  and  $x_{n+1}$  are the carrier indexes of the lowest and the highest tones respectively of the  $n$ th group of carriers, the  $(j_{\max} + 1) X_{nj}$  positions are defined as:

$$X_{nj} = x_n + \left\lfloor \frac{j(x_{n+1} - x_n)}{j_{\max}} \right\rfloor \text{ for } j = 0 \dots j_{\max}$$

$j_{\max}$  shall be chosen by the VTU-R based on the values supported by the VTU-O as specified in O-MSG2.

**Table 12-34/G.993.1 – Description of message R-B&G**

Field content	Field or macro-field type
Message descriptor	Message code (See Table 12-12.)
$j_{\max}$	1 byte
$b_i$ 's and $g_i$ 's information	B&G descriptor (See Tables 12-28 to 12-30.)

**12.4.6.3.2 Symbol types transmitted by VTU-R****12.4.6.3.2.1 R-P-MEDLEY**

R-P-MEDLEY is a wideband signal used for estimation at the VTU-O of the upstream SNR. It is made of all the allowed upstream tones modulated in 4QAM. The symbol length shall be  $N+CE$  samples.  $N$  shall be set to the value specified in ITU-T Rec. G.994.1 and  $CE$  shall be set to the value specified in O-MSG1 (see 12.4.4.2.1.3). Any change in  $CE$  shall be made at the beginning of the DMT symbol (i.e., by changing the number of samples in  $L_{CP}$ ; see 9.2.2). Windowing shall be applied at the transmitter and the overall window length  $\beta$  shall be as specified in O-SIGNATURE (see 12.4.4.2.1.1). The transmit PSD mask shall meet the power back-off requirements. The timing advance shall be applied and shall correspond to the loop length as estimated by the VTU-O. R-P-MEDLEY shall carry two bytes of information ( $b_{15} b_{14} \dots b_8$ ) and ( $b_7 b_6 \dots b_0$ ) per DMT symbol. These shall be mapped as described in Table 12-35.

**Table 12-35/G.993.1 – R-P-MEDLEY bit mapping**

Tone index	Constellation point
5, 10, 15, ..., $5n$ , ...	00
1, 11, 21, ..., $10n+1$ , ...	SOC message bits 0 & 1
2, 12, 22, ..., $10n+2$ , ...	SOC message bits 2 & 3
3, 13, 23, ..., $10n+3$ , ...	SOC message bits 4 & 5
4, 14, 24, ..., $10n+4$ , ...	SOC message bits 6 & 7
6, 16, 26, ..., $10n+6$ , ...	SOC message bits 8 & 9
7, 17, 27, ..., $10n+7$ , ...	SOC message bits 10 & 11
8, 18, 28, ..., $10n+8$ , ...	SOC message bits 12 & 13
9, 19, 29, ..., $10n+9$ , ...	SOC message bits 14 & 15

The selected constellation points shall be pseudo-randomly rotated by 0,  $\pi/2$ ,  $\pi$  or  $3\pi/2$  depending on the value of a 2-bit random number, provided by the pseudo-random bit generator defined in 12.4.4.2.2.1. Two bits shall be mapped onto each tone including DC. The pseudo-random bit sequence shall continue from one symbol to the next one.

NOTE – Between any two consecutive DMT symbols, a number of output bits of the random bit generator shall be skipped, as discussed in 12.4.4.2.2.1.

**12.4.6.3.2.2 R-P-SYNCHRO2**

R-P-SYNCHRO2 is a wideband signal that allows the VTU-O and the VTU-R to simultaneously step into the ShowTime state (in the upstream direction). It uses all the allowed upstream tones modulated in 4QAM. The symbol length shall be  $N+CE$  samples.  $N$  shall be set to the value specified in ITU-T Rec. G.994.1 and  $CE$  shall be set to the value specified in O-MSG1 (see 12.4.4.2.1.3). Windowing shall be applied at the transmitter and the overall window length  $\beta$  shall be set to the value specified in O-SIGNATURE (see 12.4.4.2.1.1). The PSD shall conform with the UPBO requirements. The overall duration of R-P-SYNCHRO2 shall be 15 DMT symbols. The value 11 shall be mapped on all the allowed downstream tones for the 5 first and the 5 last



DMT symbols. The value 00 shall be mapped on the allowed downstream tones for the 5 remaining DMT symbols. The selected constellation points shall be pseudo-randomly rotated by  $0, \pi/2, \pi, 3\pi/2$  depending on the 2-bit random sequence provided by the pseudo-random bit generator defined in 12.4.4.2.2.1. The pseudo-random bit sequence shall continue from symbol to the next one.

The scrambler shall be running free during the transmission of this R-P-SYNCHRO2.

In the upstream direction, the quadrant scrambler shall be disabled after the transmission of R-P-SYNCHRO2.

### 13 Electrical requirements

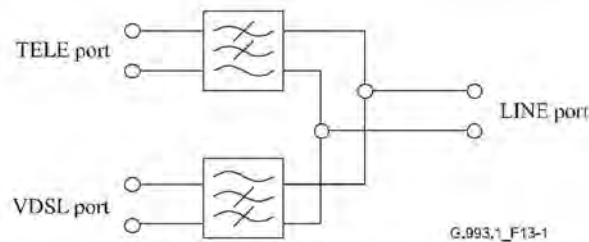
#### 13.1 Service splitters

##### 13.1.1 General

A service splitter (splitter filter) is required at both ends of the line that carries VDSL signals if existing narrow-band services are to remain unaffected by the presence of VDSL signals on the same wire-pair. The structure of the splitter filter is given in Figure 13-1. The VDSL port connects to the VDSL transceiver. The TELE port connects to the existing POTS NT or ISDN-BA NT. The TELE-LINE function is that of a low-pass filter, whereas the VDSL-LINE port function is high-pass. Exceptional isolation is required between TELE and VDSL ports to prevent undesirable interaction between VDSL and the used narrow-band service.

The splitter filter requirements are intended to guarantee the proper operation of POTS and ISDN-BA on lines that carry VDSL signals. The requirements of the high-pass filter are more dependent on the VDSL transceiver structure and may be partially combined with an all pass function of the VDSL branch.

NOTE – Splitter implementations may be subject to additional administration-imposed requirements, beyond those contained herein.



**Figure 13-1/G.993.1 – Structure of the VDSL splitter filter**

The splitter shall meet the requirements with all VDSL transceiver impedance values that are tolerated by its return loss specification. The reference impedance values associated with the TELE and VDSL ports are as follows:

- TELE port:  $Z_M$
- VDSL port:  $R_F$

The particular values of  $Z_M$  and  $R_F$  are regionally specific and specified in Annexes D, E and F.

The basic electrical requirements for the splitter are listed in Table 13-1. The values of the parameters, as well as other specific requirements, are regionally specific and described in regional specific annexes (e.g., Annexes D, E and F).

**Table 13-1/G.993.1 – Basic VDSL splitter filter electrical requirements**

#	Requirement
1	TELE port to LINE port insertion loss into $Z_M$ , and the insertion loss variation (ripple)
2	TELE port and LINE port return loss against $Z_M$ , and return loss variation (ripple) when the other port is terminated in $Z_M$
3	LINE port to VDSL port insertion loss into $R_V$ , and the insertion loss variation (ripple)
4	LINE port and VDSL port return loss against $R_V$ , and return loss variation (ripple) when the other port is terminated in $R_V$
5	TELE port to VDSL port isolation
6	The common-mode isolation between TELE and LINE ports
7	TELE port to LINE port DC resistance

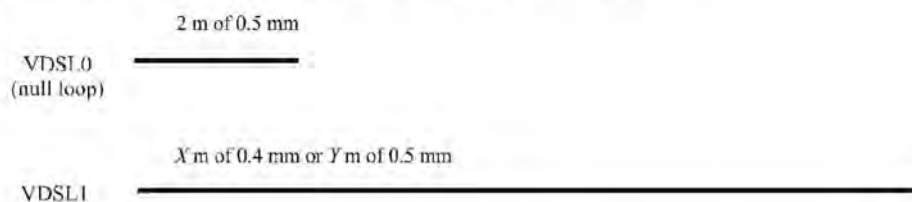
The requirements of Table 13-1 shall be met when the port, which is not in use for the test of a specific requirement, is terminated:

- with the appropriate matching impedance;
- with a mismatched impedance due to reasonable fault conditions at this port (e.g., line break, typical resistive load, ringer load, etc.).

## 14 Testing methodology

### 14.1 VDSL test loop types

Test loops characterized twisted pairs used for VDSL deployment and shall be used for testing and competitive evaluations of VDSL modems. Test loops (VDSL0 – VDSL1) presented in Figure 14-1 characterize the most generic case. Loop VDSL0 is a symbolic name for a loop with near zero length to prove that the VDSL transceiver can handle the potentially high signal levels when two transceivers are directly interconnected. Loop VDSL1 is useful for a generic range test. The values of X and Y vary for different bit rates of the system under test. Other types of test loop, which are specific for different regions, are described in Annexes D, E, and F.

**Figure 14-1/G.993.1 – Generic VDSL test loops**

NOTE – The parameter values for loop types with wire gauge 0.4 mm and 0.5 mm are region-specific. For comparative analysis the loops types TP1 (0.4 mm) and TP2 (0.5 mm) as specified in ITU-T Rec. G.996.1 may be used.

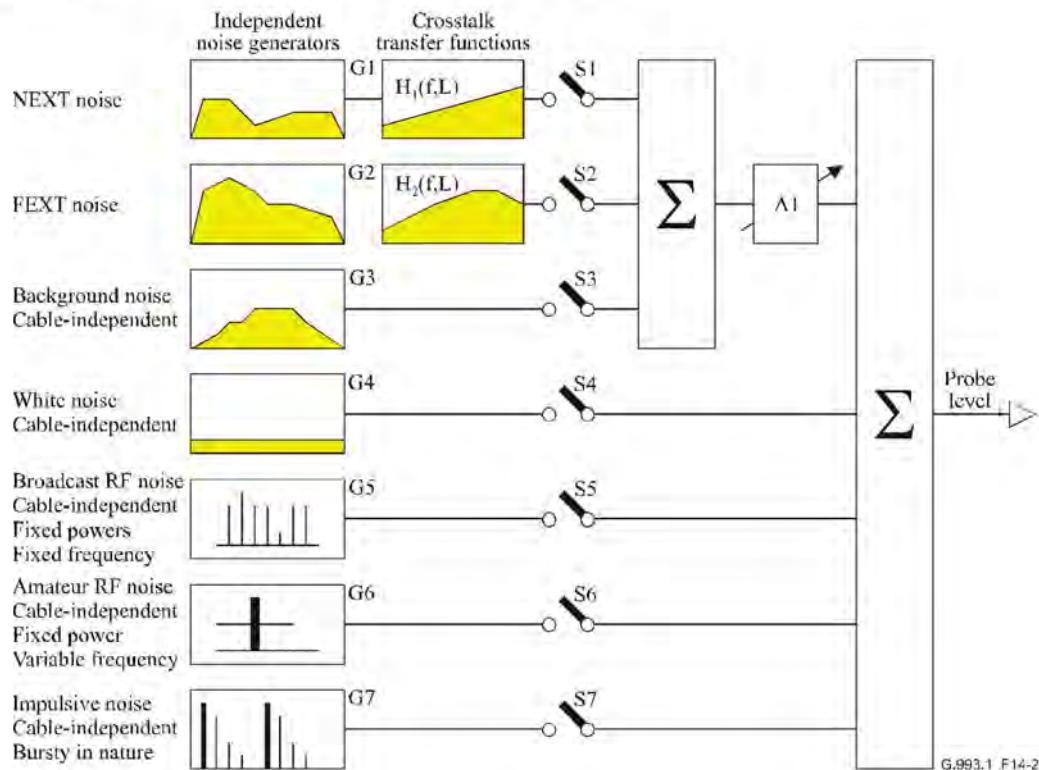
### 14.2 Impairment generators

Figure 14-2 defines a functional diagram of the composition of the impairment noise. It defines a functional description of the combined impairment noise, as it shall be probed at the receiver input of a VDSL transceiver under test.



The functional diagram has the following elements:

- The seven impairment "generators" G1 to G7 simulate the noise in the loop. Their noise characteristics are independent of the test loops and bit rates.
- Switches S1-S7 determine whether or not a specific impairment generator contributes to the total impairment during a test.
- Amplifier A1 models the property to increase the level of some generators simultaneously to perform the noise margin tests. A value of  $x$  dB means a frequency-independent increase of the level by  $x$  dB over the full VDSL band, from 0 Hz to 12 MHz. Unless otherwise specified, its gain is fixed at 0 dB.
- The square of the magnitude of the transfer functions,  $|H_1(f,L)|^2$  and  $|H_2(f,L)|^2$ , for NEXT and FEXT simulation, respectively, are defined in 14.2.1.



NOTE – Generator G7 is the only one that is symbolically shown in the time domain. Others are shown in the frequency domain.

**Figure 14-2/G.993.1 – Functional diagram of the composition of the impairment noise**

The same functional diagram shall be used for impairment tests in downstream and upstream directions. Each test has its own impairment specification. The overall impairment noise shall be characterized by the sum of the individual components as specified in the relevant subclauses.

Several deployment scenarios can be applied to VDSL testing. These scenarios are representative of the impairments that can be found in metallic access networks.

#### 14.2.1 Crosstalk noise

The crosstalk noise impairments are reflected by generators G1-G3. Their noise characteristics are independent from the test loops and bit rates.

Near-end crosstalk or NEXT shall be a Gaussian signal with the square of the magnitude of its transfer function defined as:

$$|H_1(f, L)|^2 = K_{\text{NEXT}} (1/49)^{0.6} f^{1.5} [1 - |H(f, L)|^4]$$

Similarly, the square of the magnitude of the transfer function of far-end crosstalk or FEXT is defined as:

$$|H_2(f, L)|^2 = |H(f, L)|^2 K_{\text{FEXT}} (1/49)^{0.6} L f^2$$

where:

$|H(f, L)|$  is the magnitude of loop insertion gain transfer function

$K_{\text{NEXT}}$  and  $K_{\text{FEXT}}$  are crosstalk coupling coefficients,  $K_{\text{NEXT}} = 8.818 \times 10^{-14}$ , and

$K_{\text{FEXT}} = 7.999 \times 10^{-20}$

$L$  is loop length in feet

$f$  is frequency in hertz.

The factor  $(1/49)^{0.6}$  accounts for the fact that the alien and self-noise transmit PSDs have already been scaled up to account for the effective number of disturbers of each type.

#### 14.2.1.1 Crosstalk noise model definition

The two main deployment scenarios, Fibre-To-The-Exchange (FTTEx) and Fibre-To-The-Cabinet (FTTCab), are considered for noise model definition. Each scenario results in a length-dependent PSD of noise, reflecting the distance between the exchange and the cabinet ( $L1$ ) and also distances  $L2$  and  $L3$  as described in Figure 14-3. The crosstalk to be emulated by G1 and G2 comprise of "self-crosstalk" and "alien crosstalk". The self-crosstalk is caused by the VDSL systems, and the alien-crosstalk is due to other systems. The PSD mask of the generator G1 and G2 for alien crosstalk shall both be attenuated in the FTTCab scenario by the value that reflects the attenuation of the corresponding signals while propagating from the exchange to the cabinet. For performance evaluation purposes, length  $L1$  shall be set to 1000 m, length  $L2$  shall be set equal to the length of the applicable test loop, and length  $L3$  shall be set to 0 m.

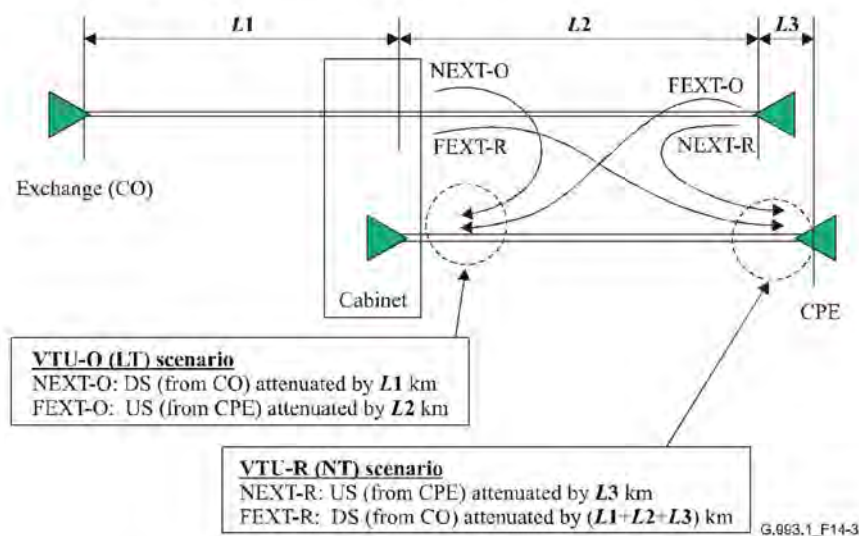


Figure 14-3/G.993.1 – Alien crosstalk noise model definition for different scenarios



The model for self-crosstalk noise in all cases shall include 20 VDSL disturbers. The model for alien crosstalk noise depends on the type and the expected amount of other (alien) DSL operating over the same binder and is regionally specific.

#### 14.2.1.2 NEXT noise generator [G1]

The NEXT noise generator represents all impairments that are identified as crosstalk noise from a predominantly Near-end origin. The [G1] noise when filtered by the NEXT crosstalk coupling function  $H_1(f, L)$  represents the contribution of all NEXT in the composite impairment noise of the test.

The PSD of the noise generator is a combination of the self-crosstalk and alien crosstalk profiles as specified in 14.2.1.4. These profiles shall be met for all frequencies of the VDSL range. For verification purposes the PSD shall be measured using a measurement bandwidth of less than 10 kHz.

$$G1.UP.\# = (XS.LT.\# \blacklozenge XA.LT.\#)$$

$$G1.DN.\# = (XS.NT.\# \blacklozenge XA.NT.\#)$$

The symbols in the above expressions are defined below:

- “#” is a placeholder for noise model “A”, “B” ... “F”.
- “XS.LT.#” and “XS.NT.#” refer to the self-crosstalk profiles defined in 12.2.1.4.
- “XA.LT.#” and “XA.NT.#” refer to the alien-crosstalk profiles defined in 12.2.1.4.
- “ $\blacklozenge$ ” defines the crosstalk sum of two PSDs as  $P_{XS} \blacklozenge P_{XA} = (P_{XS}^{1/0.6} + P_{XA}^{1/0.6})^{0.6}$  where P is the PSD in W/Hz.

The PSD of G1 is independent of the cable NEXT coupling. The magnitude response of the NEXT coupling function  $H_1(f, L)$  is specified in 14.2.1.

The noise from this generator shall be non-correlated with all other noise sources in the impairment generator and non-correlated with the VDSL system under test. The noise shall be random in nature with a near-Gaussian amplitude distribution as specified in 14.2.6.

#### 14.2.1.3 FEXT noise generator [G2]

The FEXT noise generator represents all impairments that are identified as crosstalk noise from a predominantly Far-end origin. The [G2] noise when filtered by the FEXT crosstalk coupling function  $H_2(f, L)$  represents the contribution of all FEXT in the composite impairment noise of the test.

The PSD of the noise generator is a combination of the self-crosstalk and alien-crosstalk profiles as specified in 14.2.1.4. These profiles shall be met for all frequencies in the VDSL range. The PSD shall be measured using a measurement bandwidth of less than 10 kHz.

$$G2.UP.\# = (XS.NT.\# \blacklozenge XA.NT.\#)$$

$$G2.DN.\# = (XS.LT.\# \blacklozenge XA.LT.\#)$$

The symbols in the above expressions are defined below:

- “#” is a placeholder for noise model “A”, “B” ... “F”.
- “XS.LT.#” and “XS.NT.#” refer to the self-crosstalk profiles defined in 12.2.1.4.
- “XA.LT.#” and “XA.NT.#” refer to the alien-crosstalk profiles defined in 12.2.1.4.
- “ $\blacklozenge$ ” defines the crosstalk sum of two PSDs as  $P_{XS} \blacklozenge P_{XA} = (P_{XS}^{1/0.6} + P_{XA}^{1/0.6})^{0.6}$  where P is the PSD in W/Hz.

The PSD of G2 shall be independent of the cable FEXT coupling. The magnitude response of FEXT coupling function  $H_2(f, L)$  is specified in 14.2.1.

The noise from this generator shall be non-correlated with all other noise sources in the impairment generator and non-correlated with the VDSL system under test. The noise shall be random in nature with a near-Gaussian amplitude distribution as specified in 14.2.6.

#### 14.2.1.4 Frequency domain profiles of generators [G1] and [G2]

Crosstalk noise represents all impairments that originate from systems connected to adjacent wire pairs that are coupled to the wires of the VDSL system under test. Noise generators G1 and G2 represent the equivalent of many disturbers in a real scenario with all disturbers co-located at the ends of the test loops.

##### 14.2.1.4.1 Self-crosstalk profiles

The noise profile of self-crosstalk is implementation-specific to the VDSL system under test. The transceiver manufacturers shall determine the VDSL transmit signal spectrum of the VDSL system under test at both LT and NT (VDSL.LT.# or VDSL.NT.#) over the full VDSL band as observed at the Tx port of the test set-up described in 14.3.1. The resolution bandwidth for measurement shall be 10 kHz, but regional requirements may apply.

Separate spectral profiles shall be used to describe the self-crosstalk at the LT end and at the NT end of the test loop. In the following text the "#" is a placeholder for models "A" to "F".

- The profiles XS.LT.# describe the self-crosstalk portion of an equivalent disturber co-located at the LT end of the test loop. When testing the upstream, this profile shall be applied to generator G1. When testing the downstream, this profile is applied to generator G2. The self-crosstalk profile is specified in Table 14-1.
- The profiles XS.NT.# describe the self-crosstalk portion of an equivalent disturber co-located at the NT end of the test loop. When testing the upstream, this profile is applied to generator G2. When testing the downstream, this profile is applied to generator G1. The self-crosstalk profile is specified in Table 14-1.

**Table 14-1/G.993.1 – Definition of self-crosstalk**

Cabinet	Model A	Model B	Model C
XS.LT.#	VDSL.LT.A + 8 dB	VDSL.LT.B + 8 dB	VDSL.LT.C + 8 dB
XS.NT.#	VDSL.NT.A + 8 dB	VDSL.NT.B + 8 dB	VDSL.NT.C + 8 dB
Exchange	Model D	Model E	Model F
XS.LT.#	VDSL.LT.D + 8 dB	VDSL.LT.E + 8 dB	VDSL.LT.F + 8 dB
XS.NT.#	VDSL.NT.D + 8 dB	VDSL.NT.E + 8 dB	VDSL.NT.F + 8 dB

NOTE 1 – The addition of 8 dB approximates the power generated by the sum of 20 VDSL systems operating in a multi-pair cable.

NOTE 2 – The VDSL self-crosstalk is assumed to be generated by transceivers with the same PSD template/mask as the transceiver under test, but not necessarily with the same transmit PSD.

##### 14.2.1.4.2 Alien-crosstalk profiles

Alien crosstalk models A-F are regional-specific and described in Annexes E, D and F. Separate spectral profiles shall be used to describe the alien crosstalk at the LT end and at the NT end of the test loop. In the following text, the "#" is a placeholder for models "A" to "F".

- The profiles XA.LT.# describe the alien-crosstalk portion of an equivalent disturber co-located at the LT end of the test loop. When testing the upstream, this profile shall be



applied to generator G1. When testing the downstream, this profile shall be applied to generator G2. The alien-crosstalk profiles are specified in Annexes D, E and F.

- The profiles XA.NT.# describe the alien crosstalk portion of an equivalent disturber co-located at the NT end of the test loop. When testing the upstream, this profile shall be applied to generator G2. When testing the downstream, this profile is applied to generator G1. The alien-crosstalk profiles are specified in Annexes D, E and F.

#### **14.2.2 Background noise generator [G3]**

The background noise generator G3 shall generate coloured noise. For the tests specified in this Recommendation, G3 shall be inactive and shall be set to zero.

#### **14.2.3 Additive white Gaussian noise generator [G4]**

The Additive White Gaussian Noise (AWGN) generator G4 shall have a flat PSD of  $-140$  dBm/Hz in the whole VDSL frequency band, as specified in 6.1.

#### **14.2.4 Radio noise generator [G5]**

The broadcast RF noise generator represents the discrete tone-line interference caused by amplitude modulated broadcast transmissions in the SW, MW and LW bands which ingress into the differential or transmission mode of the wire-pair. These interference sources have more temporal stability than the amateur/ham interference (noise generator [G6]) because their carrier is not suppressed. The modulation index (MI) and the carrier frequencies of broadcast transmitters are regionally-specific. Each simulated RFI threat may include several simulated AM broadcast stations in the SW, MW and LW band. For some regions the requirements are specified in Annexes D, E and F.

#### **14.2.5 Amateur radio noise generator [G6]**

The amateur radio noise generator represents a large (almost impulse-like) RF interference that has changing temporal characteristics due to the single-sideband suppressed nature of the amateur radio transmission. The interference exhibits severe temporal variations, and can be high in amplitude, and can occur anywhere within the regionally standardized HF amateur bands and at any time of day or night. Overhead wiring is especially susceptible to RF ingress of this nature. Coupling into twisted telephone wires is usually via the common mode and then into the differential mode. The amateur radio noise bands are specified in Table 14-2. The modulating base-band signal shall be speech-weighted noise as specified in ITU-T Rec. G.227. Some regional-specific amateur bands, the amateur noise power to be applied are specified in Annexes D, E and F.

**Table 14-2/G.993.1 – Amateur radio noise bands**

<b>Band start [kHz]</b>	<b>Band stop [kHz]</b>
1 800	2 000
3 500	4 000
7 000	7 300
10 100	10 150
14 000	14 350
18 068	18 168
21 000	21 450
24 890	24 990
28 000	29 700

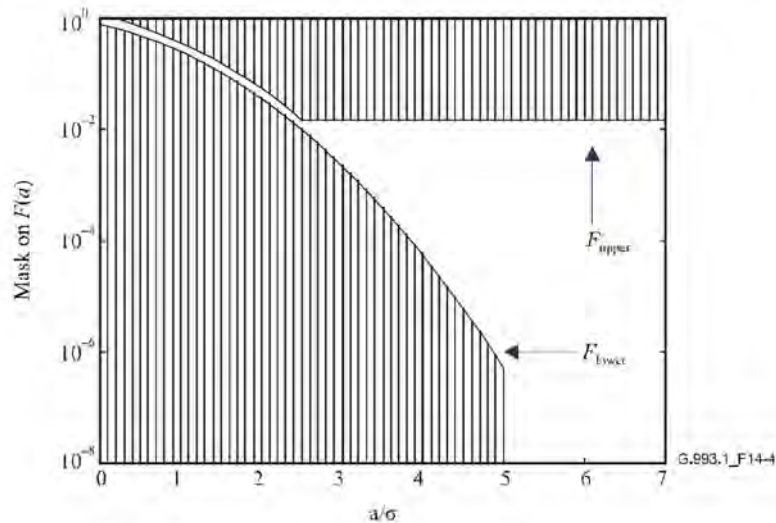
#### 14.2.6 Impulse noise model [G7]

The impulse noise generator is required to prove the burst noise immunity of the VDSL transceiver. The noise shall consist of bursts of additive white Gaussian noise (AWGN) injected onto the line with sufficient power to ensure effective erasure of the data for the period of the burst, i.e., the bit error ratio during the burst shall be approximately 0.5 (assuming FEC is not applied). The noise burst shall be applied regularly at a repetition rate of at least 1 Hz.

The duration of the burst is variable; at least values of 10, 50, 100, 250, and 500  $\mu$ s shall be supported. The AWGN shall be generated with crest-factor of 5 and flat PSD up to 12 MHz, and further continuously declined with a roll-off equal to or steeper than 12 dB per octave. The PSD of the AWGN shall be variable in the range from  $-70$  dBm/Hz to  $-140$  dBm/Hz.

#### 14.2.7 Time domain profiles of generators [G1] to [G4]

The noise as specified in the frequency domain shall be random in nature and near-Gaussian distributed, which means that the amplitude distribution function of the combined impairment noise injected at the adding element shall lie between the two boundaries as illustrated in Figure 14-4 and defined in Table 14-3.



NOTE The non-shaded area is the allowed region.

**Figure 14-4/G.993.1 – Mask for the amplitude distribution function**

The amplitude distribution function  $F(a)$  of noise  $u(t)$  is the fraction of the time that the absolute value of  $u(t)$  exceeds the value "a". From this definition, it can be concluded that  $F(0) = 1$  and that  $F(a)$  shall decrease up to the point where "a" equals the peak value of the signal. From there on,  $F(a)$  shall vanish:

$$F(a) = 0, \text{ for } a \geq |u_{peak}|$$

The boundaries on the amplitude distribution ensure that the noise is characterized by peak values that are occasionally significantly higher than the rms value of that noise (up to 5 times the rms value).



**Table 14-3/G.993.1 – Upper and lower boundaries of the amplitude distribution function of the noise**

Boundary ( $\sigma$ = rms value of noise)	Interval	Parameter	Value
$F_{lower}(a) = (1 - \varepsilon) \times \left\{ 1 - \operatorname{erf}\left(a / \sigma\right) / \sqrt{2} \right\}$	$0 \leq a / \sigma < CF$	crest factor	$CF = 5$
$F_{lower}(a) = 0$	$CF \leq a / \sigma < \infty$	Gaussian gap	$\varepsilon = 0.1$
$F_{upper}(a) = (1 + \varepsilon) \times \left\{ 1 - \operatorname{erf}\left(a / \sigma\right) / \sqrt{2} \right\}$	$0 \leq a / \sigma < A$		$A = CF/2 = 2.5$
$F_{upper}(a) = (1 + \varepsilon) \times \left\{ 1 - \operatorname{erf}\left(A / \sqrt{2}\right) \right\}$	$A \leq a / \sigma < \infty$	Gaussian gap	$\varepsilon = 0.1$

The meaning of the parameters in Table 14-3 is as follows:

- CF denotes the minimum crest factor of the noise, that characterizes the ratio between the absolute peak value and rms value ( $CF = |u_{peak}|/u_{rms}$ ).
- $\varepsilon$  denotes the Gaussian gap that indicates how close near-Gaussian noise approximates true Gaussian noise.
- A denotes the point beyond which the upper limit is alleviated to allow the use of noise signals of practical repetition length.

### 14.3 Transmission performance tests

VDSL systems shall be tested to verify  $BER \leq 10^{-7}$  and a minimum noise margin of 6 dB using the test set-up specified in 14.3.1 and test procedures specified in 14.3.2. This noise margin indicates the amount of increase of crosstalk noise or impulse noise level that the system can tolerate under operational conditions while still ensuring required transmission quality.

#### 14.3.1 Test setup

Figure 14-5 illustrates the functional description of the test set-up. It shall include:

- the relevant test loop, as specified in 14.1 or Annexes D, E, F;
- the impairment noise generator, as specified in 14.2;
- an Adding Element to add the relevant impairment noise to the test loop;
- a high impedance, and well balanced (e.g., better than 60 dB balance across the whole VDSL band) differential voltage probe connected with level detectors such as a spectrum analyser or a true RMS volt-meter.

NOTE – Test Loop VDSL0 may be used for calibrating and verifying the correct settings of impairment noise generators when performing performance tests.

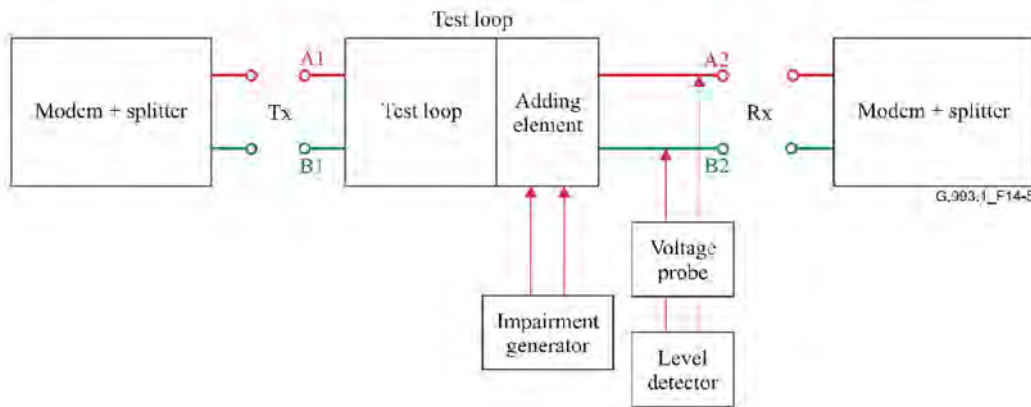
The transfer function and impedance of the test-loop between port Tx (node pairs A1, B1) and port Rx (node pair A2, B2) shall be properly adjusted to take full account of non-zero insertion loss and non-infinite shunt impedance of the adding element and impairment generator. This is to ensure that the insertion of the generated impairment signals does not appreciably load the line.

The balance about earth, observed at port Tx, at port Rx, and at the tips of the voltage probe shall exhibit a value that is 10 dB greater than the transceiver under test. This is to ensure that the impairment generator and monitor function do not appreciably deteriorate the balance about earth of the transceiver under test.

The signal flow through the test set-up shall be from port Tx to port Rx. Measuring upstream and downstream performance requires an interchange of transceiver position and test loop end.

The received signal level at port Rx shall be measured between node A2 and B2, when port Tx as well as port Rx are terminated with the VDSL transceivers under test. The impairment generator

shall be switched off during this measurement. The transmitted signal level at port Tx shall be measured between node A1 and B1, under the same conditions.



**Figure 14-5/G.993.1 – Functional description of the set-up of the performance tests**

The impairment noise generator shall be as defined in 14.2. The level of inserted impairment noise shall be measured at port Rx, between node A2 and B2, while port Tx as well as port Rx are terminated with the Termination impedance  $R_V$ . The signal and the impairment noise levels shall be probed with a well-balanced differential voltage probe. The differential impedance between the tips of the probe shall be higher than the shunt impedance of 100 k $\Omega$  in parallel with 10 pF. Figure 14-5 shows the probe position when measuring the Rx signal level at the LT or NT receiver. Measuring the Tx signal level requires the connection of the tips to node pair [A1, B1].

The various levels of signals and impairment noise specified in this Recommendation are defined at the Tx or Rx side of this set-up. For all power measurements, probing an RMS-voltage of  $U_{RMS}$  [V] at the test point terminated by the resistive impedance of  $R_V$  means the power level of  $P$  [dBm] over the full band equals:

$$P = 10 \log_{10} \left( \frac{U_{RMS}^2}{R_V} \cdot 1000 \right), \text{ in dBm}$$

Probing an RMS-voltage  $U_{RMS}$  [V] in this set-up within a small frequency band of  $f$  [Hz] means an average power spectral density level of PSD [dBm/Hz] within that filtered band that equals:

$$PSD = 10 \log_{10} \left( \frac{U_{RMS}^2}{R_V} \cdot \frac{1000}{\Delta f} \right), \text{ in dBm/Hz}$$

The bandwidth  $f$  shall identify the noise bandwidth of the filter, but not the 3 dB bandwidth. The value of  $f$  shall be 10 kHz, but regional requirements may apply.

### 14.3.2 Measuring noise margin

Before start-up of the VDSL transceiver under test, the level and shape of the crosstalk noise or impulse noise are adjusted so that the level observed at port Rx in Figure 14-5 meets the impairment level specification. This relative level is referred to as 0 dB. The transceiver link is subsequently activated, and the bit error ratio of the link is monitored.

By adjusting the gain of amplifier A1 in Figure 14-2, the crosstalk noise level of the impairment generators is then increased (equally over the full VDSL frequency band) until the bit error ratio is approximately  $10^{-7}$ . This BER will be achieved at an increase of noise of  $x$  dB, with a small uncertainty of  $x$  dB. The value  $x$  is defined as the noise margin with respect to a standard noise



model and may (optionally) be used to indicate the sensitivity of the system under test to changes in BER.

NOTE – It is expected that the noise level that brings the BER to  $10^{-7}$  is very close to the level associated with a BER of  $10^{-5}$  (usually within a fraction of a dB for a coded system). In order to speed up the iterative search for noise margins, it is a practical approach to start the margin search for a BER of  $10^{-5}$ , and then search for the noise level associated with a BER of  $10^{-7}$ . The BER requirement of  $10^{-7}$  remains valid in order to pass the transmission performance test.

The noise margins shall be measured for upstream as well as downstream transmission under all relevant test loops and noise generator settings.

### 14.3.3 Noise generator sets for different test scenarios

The set of noise generators valid for VDSL performance tests to be carried out to prove adequate upstream and downstream performance is regionally specific. For some regions the set of noise generators is specified in Annexes D, E and F.

## Annex A

### Bandplan A

Table A.1 defines the frequencies and usage of Bandplan A as illustrated in Figure A.1.

NOTE – Bandplan A is formerly called Plan 998.

Table A.1/G.993.1 – Bandplan A

	[MHz]	Direction
$f_0-f_1$	0.025-0.138	Usage and Directional are optional
$f_1-f_2$	0.138-3.75	Downstream
$f_2-f_3$	3.75-5.2	Upstream
$f_3-f_4$	5.2-8.5	Downstream
$f_4-f_5$	8.5-12	Upstream

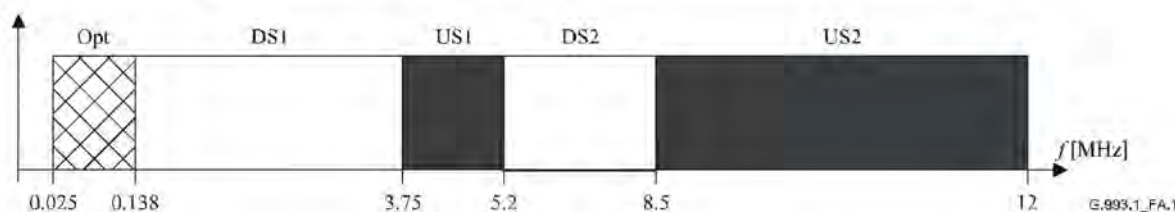


Figure A.1/G.993.1 – Bandplan A

## Annex B

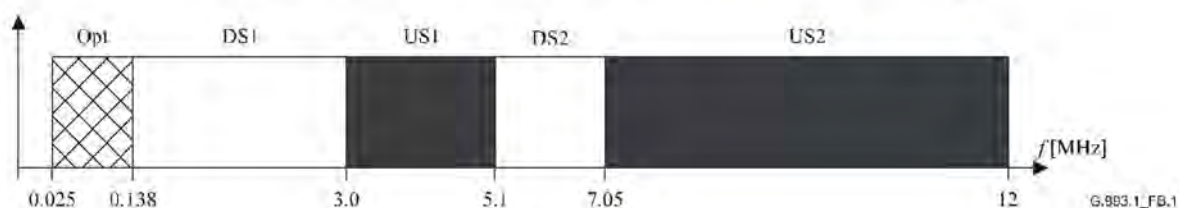
### Bandplan B

Table B.1 defines the frequencies and usage of Bandplan B as illustrated in Figure B.1.

NOTE – Bandplan B is formerly called Plan 997.

**Table B.1/G.993.1 – Bandplan B**

	[MHz]	Direction
$f_0-f_1$	0.025-0.138	Usage and Directional are optional
$f_1-f_2$	0.138-3.0	Downstream
$f_2-f_3$	3.0-5.1	Upstream
$f_3-f_4$	5.1-7.05	Downstream
$f_4-f_5$	7.05-12	Upstream



**Figure B.1/G.993.1 – Bandplan B**

## Annex C

### Bandplan C

NOTE – This annex is intended for use in Sweden only.

Table C.1 defines the frequencies and usage of Bandplan C as illustrated in Figure C.1.

$F_x$  is a variable frequency.

**Table C.1/G.993.1 – Bandplan C**

	[MHz]	Direction
$f_0-f_1$	0.025-0.138	Usage and Directional are optional
$f_1-f_2$	0.138-2.5	Downstream
$f_2-f_3$	2.5-3.75	Upstream
$f_3-f_4$	3.75- $F_x$	Downstream
$f_4-f_5$	$F_x$ -12	Upstream

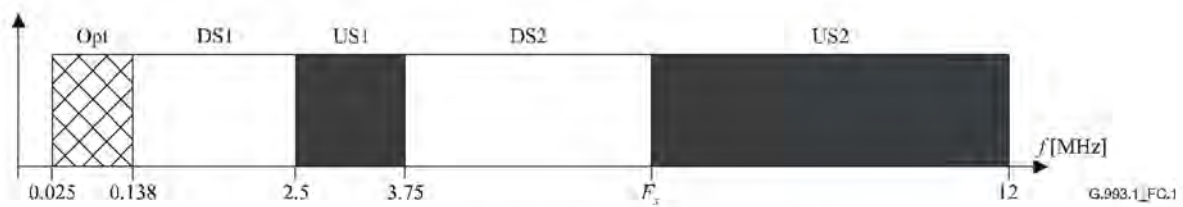


Figure C.1/G.993.1 – Bandplan C

## Annex D

### Requirements for Region A (North America)

#### D.1 Physical interface

##### D.1.1 Bandplan

Bandplan A as specified in Annex A shall be used.

##### D.1.2 Wideband transmit power

As specified in [American National Standard Institute (ANSI)].

##### D.1.3 PSD of the transmit signal

As specified in [ANSI].

##### D.1.4 Termination impedance

As specified in [ANSI].

##### D.1.5 Reference PSD

The values of PSD\_REF for noise environments as specified in 6.3.1 and transmit signal PSDs as specified in 6.3.1 shall be as defined in [ANSI].

#### D.2 Testing methodology

##### D.2.1 Noise models

###### D.2.1.1 Alien crosstalk noise models

As specified in [ANSI].

###### D.2.1.2 RFI noise generators models

As specified in [ANSI].

##### D.2.2 Test loops

As specified in [ANSI].

##### D.2.3 Service splitters and electrical characteristics

As specified in [ANSI].

## **Annex E**

### **Requirements for Region B (Europe)**

#### **E.1 Physical interface**

##### **E.1.1 Bandplan**

Bandplan A as specified in Annex A or Bandplan B as specified in Annex B may be used with restrictions specified in [ETSI].

##### **E.1.2 Wideband transmit power**

As specified in [ETSI].

##### **E.1.3 PSD of the transmit signal**

As specified in [ETSI].

##### **E.1.4 Termination impedance**

As specified in [ETSI].

##### **E.1.5 Reference PSD**

The values of PSD\_REF for noise environments as specified in 6.3.1 and transmit signal PSDs as specified in 6.3.1 shall be as defined in [ETSI].

#### **E.2 Testing methodology**

##### **E.2.1 Noise models**

###### **E.2.1.1 Alien crosstalk noise models**

As specified in [ETSI].

###### **E.2.1.2 RFI noise generators models**

As specified in [ETSI].

##### **E.2.2 Test loops**

As specified in [ETSI].

##### **E.2.3 Service splitters and electrical characteristics**

As specified in [ETSI].



## Annex F

### Regional requirements for environment coexisting with TCM-ISDN DSL as defined in Appendix III/G.961

#### F.1 Bandplan and PSD masks

##### F.1.1 Bandplan

The bandplan shall be compliant to Bandplan A specified in Annex A. Subsets composed of at least one downstream band and one upstream band among DS1, US1, DS2 and US2 may be implemented.

##### F.1.2 Transmit signal PSD masks

###### F.1.2.1 VDSL system operating in the frequency region above POTS band

The frequencies above 138 kHz are used for VDSL. The use of the optional band between 25 kHz and 138 kHz is specified in Table F.2.

A nominal PSD of  $-60$  dBm/Hz applies across the whole transmit-band frequency range. The PSD mask defines the transmit power spectral density limitation, and is defined as 3.5 dB above the nominal PSD in dBm/Hz. The PSD requirements are specified in Table F.1 for VTU-O transmitter (downstream) and Table F.2 for VTU-R transmitter (upstream), and shall be measured at the U interface point defined in Figure 5-2, where the U interface point corresponds to LINE port defined in Figure F.1.

NOTE 1 – This annex specifies a full flat transmit signal PSD of  $-60$  dBm/Hz as a widely common PSD.

NOTE 2 – The stop-band PSD requirements specified in this annex are compliant to those in 6.2.2. The requirements are also applied to the out-of-bands below 0.138 MHz and above 12 MHz in this annex, excepting that the transition band of 0.018 MHz ( $= 0.138$  MHz  $- 0.12$  MHz) is adopted at the band separating frequency of 0.138 MHz.

**Table F.1/G.993.1 – VTU-O transmit PSD requirements (VDSL above POTS band)**

Band attribute	Frequency band $f$ [MHz]	Maximum PSD limitation (PSD mask) [dBm/Hz]	Maximum power limitation in a 1-MHz sliding window [dBm]	Average wideband power limitation [dBm]
	$0 < f < 0.12$	$-120$	–	8.4
	$0.12 \leq f \leq 0.138$	$-60 + (50/0.018) \times (f - 0.138)$	–	
DS1	$0.138 < f < 3.75$	$-60 + 3.5 (= -56.5)$	–	
	$3.75 \leq f \leq 3.925$	$-80 - (20/0.175) \times (f - 3.75)$	–	
	$3.925 < f < 5.025$	$-100$	$-50$	
	$5.025 \leq f \leq 5.2$	$-80 + (20/0.175) \times (f - 5.2)$	–	
DS2	$5.2 < f < 8.5$	$-60 + 3.5 (= -56.5)$	–	
	$8.5 \leq f \leq 8.675$	$-80 - (20/0.175) \times (f - 8.5)$	–	
	$8.675 < f < 30$	$-100$	$-52$	
	$30 \leq f < \infty$	$-120$	–	–



**Table F.1/G.993.1 – VTU-O transmit PSD requirements (VDSL above POTS band)**

NOTE 1 – All PSD and power measurements are in 100  $\Omega$ .

NOTE 2 – The maximum PSD shall be measured with a 10-kHz resolution bandwidth.

NOTE 3 – The maximum power in a 1-MHz sliding window is measured with a 1-MHz resolution bandwidth.

NOTE 4 – The requirements for the stop-band PSD are compliant to those in 6.2.2, excepting transition band below 138 kHz.

**Table F.2/G.993.1 – VTU-R transmit PSD requirements (VDSL above POTS and ISDN bands)**

Band attribute	Frequency band $f$ [MHz]	Maximum PSD limitation (PSD mask) [dBm/Hz]	Maximum power limitation in a 1-MHz sliding window [dBm]	Average wideband power limitation [dBm]
	$0 < f < 0.12$	-120	–	7.0
	$0.12 \leq f < 0.225$	-110	–	
	$0.225 \leq f < 3.575$	-100	–	
	$3.575 \leq f \leq 3.75$	$-80 + (20/0.175) \times (f - 3.75)$	–	
US1	$3.75 < f < 5.2$	$-60 + 3.5 (= -56.5)$	–	
	$5.2 \leq f \leq 5.375$	$-80 - (20/0.175) \times (f - 5.2)$	–	
	$5.375 < f < 8.325$	-100	-52	
	$8.325 \leq f \leq 8.5$	$-80 + (20/0.175) \times (f - 8.5)$	–	
US2	$8.5 < f < 12$	$-60 + 3.5 (= -56.5)$	–	
	$12 \leq f \leq 12.175$	$-80 - (20/0.175) \times (f - 12)$	–	
	$12.175 < f < 30$	-100	-52	–
	$30 \leq f < \infty$	-120	–	

NOTE 1 – All PSD and power measurements are in 100  $\Omega$ .

NOTE 2 – The maximum PSD shall be measured with a 10-kHz resolution bandwidth.

NOTE 3 – The maximum power in a 1-MHz sliding window is measured with a 1-MHz resolution bandwidth.

NOTE 4 – The requirements for the stop-band PSD are compliant to those in 6.2.2.

**F.1.2.2 VDSL system operating in the frequency region above TCM-ISDN DSL band**

The frequencies above 640 kHz are used for VDSL. The frequencies below 320 kHz are used for TCM-ISDN DSL, and the band between 320 kHz and 640 kHz are used for guardband.

The nominal PSD of -60 dBm/Hz applies across the whole transmit-band frequency range. The PSD mask defines the transmit power limitation, and is defined as 3.5 dB above the nominal PSD in dBm/Hz. The PSD requirements are specified in Table F.3 for VTU-O transmitter (downstream) and Table F.2 for VTU-R transmitter (upstream), and shall be measured at the U interface point defined in Figure 5-2, where the U interface point corresponds to LINE port defined in Figure F.1.

NOTE – The stop-band PSD requirements specified in this annex are compliant to those in 6.2.2. The requirements are also applied to the out-of bands below 0.64 MHz and above 12 MHz in this annex.

**Table F.3/G.993.1 – VTU-O transmit PSD requirements  
(VDSL above TCM-ISDN DSL band)**

Band attribute	Frequency band $f$ [MHz]	Maximum PSD limitation (PSD mask) [dBm/Hz]	Maximum power limitation in a 1-MHz sliding window [dBm]	Average wideband power limitation [dBm]
	$0 < f < 0.12$	–120	–	8.1
	$0.12 \leq f < 0.225$	–110	–	
	$0.225 \leq f < 0.465$	–100	–	
	$0.465 \leq f \leq 0.640$	$-60 + (40/0.175) \times (f - 0.64)$	–	
DS1	$0.640 < f < 3.75$	$-60 + 3.5 (= -56.5)$	–	
	$3.75 \leq f \leq 3.925$	$-80 - (20/0.175) \times (f - 3.75)$	–	
	$3.925 < f < 5.025$	–100	–50	
	$5.025 \leq f \leq 5.2$	$-80 + (20/0.175) \times (f - 5.2)$	–	
DS2	$5.2 < f < 8.5$	$-60 + 3.5 (= -56.5)$	–	
	$8.5 \leq f \leq 8.675$	$-80 - (20/0.175) \times (f - 8.5)$	–	
	$8.675 < f < 30$	–100	–52	
	$30 \leq f < \infty$	–120	–	

NOTE 1 – All PSD and power measurements are in 100  $\Omega$ .

NOTE 2 – The maximum PSD shall be measured with a 10-kHz resolution bandwidth.

NOTE 3 – The maximum power in a 1-MHz sliding window is measured with a 1-MHz resolution bandwidth.

NOTE 4 – The requirements for the stop-band PSD are compliant to those in 6.2.2.

### **F.1.2.3 VDSL system with PSD reduction function in the frequency region below 1.104 MHz**

The PSD reduction requirements are specified in Table F.4 for VTU-O transmitter (downstream), and shall be measured at the U interface point defined in Figure 5-2, where the U interface point corresponds to LINE port defined in Figure F.1.

NOTE – The stop-band PSD requirements specified in 6.2.2 are applied to PSD reduction function below 1.104 MHz in this annex.



**Table F.4/G.993.1 – VTU-O transmit PSD requirements (VDSL with PSD reduction function below 1.104 MHz)**

Band attribute	Frequency band $f$ [MHz]	Maximum PSD limitation (PSD mask) [dBm/Hz]	Maximum power limitation in a 1-MHz sliding window [dBm]	Average wideband power limitation [dBm]
	$0 < f < 0.12$	-120	–	7.8
	$0.12 \leq f < 0.225$	-110	–	
	$0.225 \leq f < 0.850$	-100	–	
	$0.850 \leq f \leq 1.104$	$-60 + (40/0.254) \times (f - 1.104)$	–	
DS1	$1.104 < f < 3.75$	$-60 + 3.5 (= -56.5)$	–	
	$3.75 \leq f \leq 3.925$	$-80 - (20/0.175) \times (f - 3.75)$	–	
	$3.925 < f < 5.025$	-100	-50	
	$5.025 \leq f \leq 5.2$	$-80 + (20/0.175) \times (f - 5.2)$	–	
DS2	$5.2 < f < 8.5$	$-60 + 3.5 (= -56.5)$	–	
	$8.5 \leq f \leq 8.675$	$-80 - (20/0.175) \times (f - 8.5)$	–	
	$8.675 < f < 30$	-100	-52	
	$30 \leq f < \infty$	-120	–	–
NOTE 1 – All PSD and power measurements are in 100 $\Omega$ .				
NOTE 2 – The maximum PSD shall be measured with a 10-kHz resolution bandwidth.				
NOTE 3 – The maximum power in a 1-MHz sliding window is measured with a 1-MHz resolution bandwidth.				
NOTE 4 – The requirements for the stop-band PSD are compliant to those in 6.2.2. The stop-band PSD requirements are also applied for the transition band below 1.104 MHz.				

**F.1.2.4 Transmit notches**

As defined in 6.2.4, the maximum PSD within the amateur radio bands shall be able to be reduced below -80 dBm/Hz. In order to reduce egression to amateur radio receivers located in Region 3 that receive amateur radio frequencies from Regions 1, 2, and 3 (see Figure II.1), the bands to be notched are defined in Table 6-2.

**F.1.2.5 Upstream power back-off (UPBO) PSD masks**

As defined in 6.3.2, the VTU-R shall explicitly estimate the electrical length of its line,  $kl_0$ , and use this value to calculate the transmit PSD mask  $TxPSD(kl_0, f)$ . The VTU-R shall then adapt its transmit signal to conform to the mask  $TxPSD(kl_0, f)$  given below.  $TxPSD(kl_0, f)$  given below is maximum PSD limitation, and is defined as 3.5 dB above the nominal PSD.

$$TxPSD(kl_0, f) = \min \left[ \left\{ PSDREF(f) + kl_0 \sqrt{f} \right\}, PSD_0(f) \right] \text{ [dBm/Hz]}$$

where  $PSD_0(f)$  is the VTU-R transmit mask in dBm/Hz defined in Table F.2, and  $kl_0 \sqrt{f}$  is an approximation of the loop attenuation in dB. Assuming electrical length  $kl_0$  to be  $k \times l_0$ ,  $l_0$  and  $k$  represent physical loop length and attenuation coefficient, respectively.

The reference PSD,  $PSDREF(f)$ , is a function of frequency but is independent of loop length, type of cable, and noise models.  $PSDREF(f)$  shall be as given below.

$$PSDREF(f) = \begin{cases} \text{Band US1: } -56.5 - 10.20 \times 10^{-3} \sqrt{f} : 3.75 \times 10^6 < f < 5.2 \times 10^6 \\ \text{Band US2: } -56.5 - 6.419 \times 10^{-3} \sqrt{f} : 8.5 \times 10^6 < f < 12 \times 10^6 \end{cases} \text{ [dBm/Hz]}$$

where  $f$  in Hz.

The values of  $k$ ,  $k_1$  and  $k_2$ , which are used to define the above values of  $10.20 \times 10^{-3} (= k_1 l_{ref1})$  and  $6.419 \times 10^{-3} (= k_2 l_{ref2})$  in  $PSDREF(f)$  are calculated at the centre frequencies of Band US1 and Band US2,  $4.475 \times 10^6$  Hz and  $10.25 \times 10^6$  Hz respectively, by assuming 0.4-mm PE cable defined in F.3.1 (also see Table F.6), and are given below.  $PSDREF(f)$  also assumes  $l_{ref1} = 375$  m and  $l_{ref2} = 225$  m.

$$k = \begin{cases} \text{Band US1: } k_2 = 2.719 \times 10^{-5} : 3.75 \times 10^6 < f < 5.2 \times 10^6 \\ \text{Band US2: } k_2 = 2.853 \times 10^{-5} : 8.5 \times 10^6 < f < 12 \times 10^6 \end{cases} \text{ [dB/(m}\sqrt{\text{Hz)}}]$$

where  $f$  in Hz, and  $l_{ref1}$ ,  $l_{ref2}$  in m.

The VTU-R transmit PSD with power back-off,  $TxPSD(kl_0, f)$ , shall be measured with a 10-kHz resolution bandwidth, and with using 0.4-mm PE cable defined in F.3.1 (abbreviated by TP), where the loop lengths  $l_0$  are parameters to check the conformance of  $TxPSD(kl_0, f)$ . The equation below gives the VTU-R transmit PSD mask with power back-off for a test loop length of  $l_0$  m for conformance purpose.

$$TxPSD(kl_0, f) = \begin{cases} \min[-56.5 + k_1(l_0 - l_{ref1})\sqrt{f}, -56.5] : 3.75 \times 10^6 < f < 5.2 \times 10^6 \\ \min[-56.5 + k_2(l_0 - l_{ref2})\sqrt{f}, -56.5] : 8.5 \times 10^6 < f < 12 \times 10^6 \end{cases} \text{ [dBm/Hz]}$$

where  $f$  in Hz,  $l_0$  in m, and  $k_1 = 2.719 \times 10^{-5}$ ,  $k_2 = 2.853 \times 10^{-5}$ ,  $l_{ref1} = 375$  m,  $l_{ref2} = 225$  m.

## F.2 Service splitter

### F.2.1 Introduction

Requirements for a POTS splitter appropriate to Japan are specified in F.2.2. A VDSL using the frequencies from 138 kHz up to 12 MHz enables coexistent operation with POTS on the same wire-pair by using the POTS splitter.

Requirements for an ISDN splitter appropriate to Japan are specified in F.2.3. A VDSL using the frequencies from 640 kHz up to 12 MHz enables coexistent operation with either TCM-ISDN DSL or POTS on the same wire-pair by using the ISDN splitter.

### F.2.2 POTS splitter

#### F.2.2.1 General definition

Requirements for a POTS splitter appropriate to Japan for use with ADSL (ITU-T Recs G.992.1 and G.992.3) using the frequencies from 25 kHz up to 1.104 MHz are specified in clause E.4/G.992.3, where the splitter installed at the VTU-R-side end is called remote POTS splitter, and the splitter installed at the VTU-O-side end is called CO POTS splitter.

Requirements for a POTS splitter appropriate to Japan for use with a VDSL using the frequencies from 138 kHz up to 12 MHz are specified below. The POTS splitter consists of a low-pass filter (LPF) function, and the function may be implemented either internally to VTU-x modem or externally, where  $x = R$  or  $O$ . In each case, all requirements specified below shall be met. A high pass-filter function (HPF) is part of the VTU-R and VTU-O, and specific requirements are not defined as in the case of ADSL related ITU-T Recommendations.



### F.2.2.2 Requirements

The POTS splitter designed for use with the VDSL shall be compliant to the requirements specified in clause E.4/G.992.3 for the frequencies from DC to 1.104 MHz. Besides, the POTS splitter shall be also compliant to the requirements for the frequencies from 1.104 MHz to 12 MHz as specified below.

- 1) The attenuation of LPF of the POTS splitter (i.e., the difference in attenuation measured with and without inserting LPF) shall be greater than 55 dB for the frequencies from 1.104 MHz to 12 MHz. The test method is defined in Figures E.26/G.992.3 and E.27/G.992.3, where proper values of C and L (e.g.,  $C \geq 0.2 \mu\text{F}$  and  $L \geq 5 \text{ mH}$ ) should be set for the test frequency band.
- 2) The insertion loss caused by loading LPF of the POTS splitter shall be less than 1.5 dB for the frequencies from 1.104 MHz to 12 MHz. The test method is defined in Figures E.28/G.992.3 and E.29/G.992.3, where proper values of C and L (e.g.,  $C \geq 0.2 \mu\text{F}$  and  $L \geq 5 \text{ mH}$ ) should be set for the test frequency band.
- 3) The return loss caused by loading LPF of the POTS splitter shall be greater than 12 dB against the reference impedance of  $100 \Omega$  for the frequencies from 1.104 MHz to 12 MHz. The test method is defined in Figure E.30/G.992.3.
- 4) The longitudinal balance of the POTS splitter shall be greater than 40 dB for the frequencies from 1.104 MHz to 12 MHz. The test method is defined in Figures E.31/G.992.3 and E.32/G.992.3, where proper values of C and L (e.g.,  $C \geq 0.2 \mu\text{F}$  and  $L \geq 5 \text{ mH}$ ) should be set for the test frequency band.

### F.2.3 ISDN splitter

The requirements for the ISDN splitter for use with a VDSL using the frequencies from 640 kHz up to 12 MHz is specified in this clause, where ISDN is TCM-ISDN DSL. Electrical characteristics of the ISDN splitter specified in this clause shall support both TCM-ISDN DSL and POTS as a coexistent service line with the VDSL.

#### F.2.3.1 Splitter LPF and HPF functions

The requirements for the ISDN splitters, one installed at the VTU-R-side end and the other installed at the VTU-O-side end, are specified. The requirements are the same for the splitters at both side ends. The splitter functions consist of a low-pass filter (LPF) function and a high-pass filter (HPF) function. Each function may be implemented either internally to VTU-x modem or externally, where  $x = \text{R or O}$ . Possible cases for internal or external implementation are shown in Figure F.1. In each case, all requirements specified shall be met.

In Figure F.1,  $R_T$  represents a terminal impedance of the transceiver function in VTU-x modem, and defined in F.2.3.2.3 for use in test. Each port of the splitter consists of two terminals, L1 and L2. LINE port is to be connected to the line (2-wire pair). TELE port is to be connected to NT (Network Termination function) or LT (Line termination function) of ISDN or POTS. VDSL(HPF) port is to be connected to VTU-x modem with HPF function of the splitter. VDSL( $R_T$ ) port is to be connected to VTU-x modem without LPF and HPF functions of the splitter.

$C_{\text{OPT}}$  in Type J1<sub>opt</sub> shown in Figure F.1 b) is a DC blocking capacitance of  $0.12 \mu\text{F}$  to protect ISDN or POTS against DC faults at 2-wire pair between the external LPF splitter and VTU-x modem. Equipping  $C_{\text{OPT}}$  with the external LPF splitter is optional.



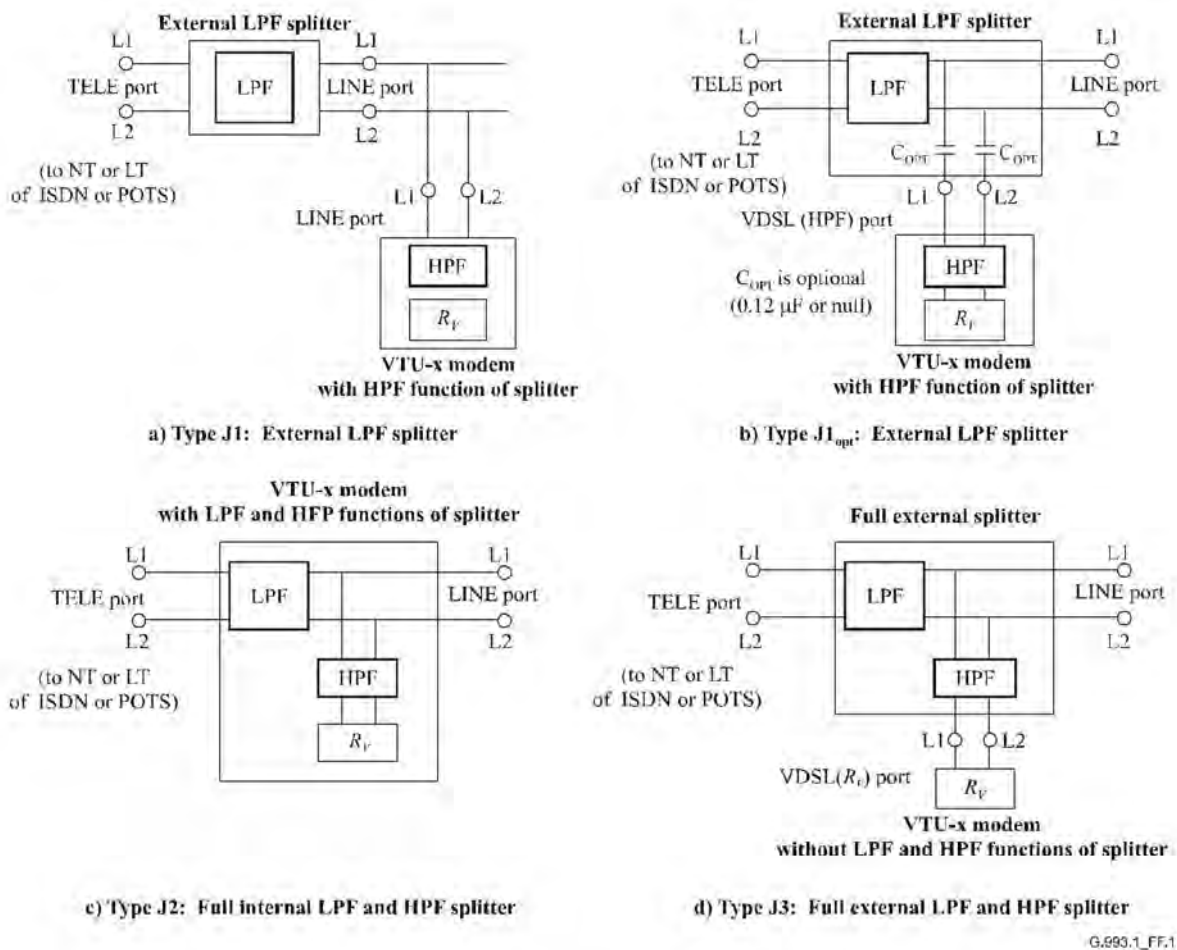


Figure F.1/G.993.1 – ISDN splitter LPF and HPF function location

### F.2.3.2 General definition

#### F.2.3.2.1 Test frequency band

Three bands of frequencies are used for test.

- Voiceband frequencies: DC and 0.2 kHz to 4.0 kHz ( $0.2 \text{ kHz} \leq f \leq 4.0 \text{ kHz}$ )
- ISDN band frequencies: DC and 4.0 kHz to 320 kHz ( $4.0 \text{ kHz} < f \leq 320 \text{ kHz}$ )
- VDSL band frequencies: 640 kHz to 12 MHz ( $640 \text{ kHz} \leq f \leq 12 \text{ MHz}$ )

The frequencies between 320 kHz to 640 kHz ( $320 \text{ kHz} < f < 640 \text{ kHz}$ ) constitute the guardband. The specific requirements in the guardband are not defined, and test is not performed for the guardband. It is, however, expected that LPF and HPF should behave well in the guardband.

#### F.2.3.2.2 Single-ended test

Single-ended test is performed for each side splitter, VTU-R-side end or VTU-O-side end. The requirements specified in F.2.3 are for a single-end splitter.

#### F.2.3.2.3 $R_V$ definition used in test

$R_V$  is defined as a terminal impedance of the transceiver function in VTU-x modem to facilitate test of the splitter independently of actual VTU-x modem implementation.

$R_V$  for voice and ISDN band test shall be ZHP as defined in Figure F.2.  $R_V$  of an open impedance is also used for voice and ISDN band test to simulate the case that VTU-x modem is not connected to the line and only either POTS or ISDN NT/LT is connected to the line through the splitter.

$R_V$  for VDSL band test shall be pure resistive 100  $\Omega$ .

NOTE –  $R_V$  also represents the maximum permissible input capacitance of the transceiver function in VTU-x modem. The requirements are specified in F.2.3.6.

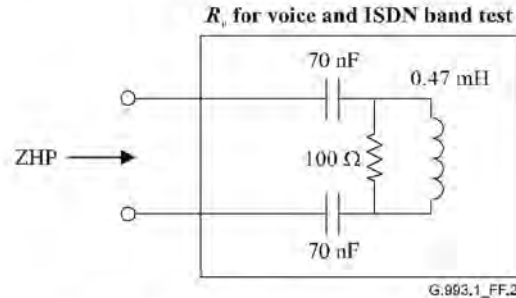


Figure F.2/G.993.1 – ZHP definition as  $R_V$  for voice and ISDN band test

### F.2.3.3 Signal requirement

#### F.2.3.3.1 DC signal requirement

The splitter shall ensure normal operation of DC voltage and current superimposed on the line from the central office (CO) side for remote power feeding and maintenance test purposes. The splitter shall also ensure normal operation of a POTS ringing signal.

##### F.2.3.3.1.1 DC voltage

The splitter shall ensure normal operation of the L1-to-L2 DC voltage, defined below, imposed at TELE and LINE ports of the splitter. The requirements shall be also taken into account at VDSL(HPF) and VDSL( $R_V$ ) ports to protect against an accidental line connection.

POTS: 0 V to ( $\pm 53$  V);

ISDN: 0 V to ( $\pm 63$  V);

Maintenance test:  $\pm 120$  V (10 s Max).

##### F.2.3.3.1.2 DC current

The splitter shall ensure normal operation of the L1-to-L2 DC current, defined below, applied at TELE and LINE ports of the splitter. The requirements shall be also taken into account at VDSL(HPF) and VDSL( $R_V$ ) ports to protect against an accidental line connection.

POTS: 0 mA to 130 mA

ISDN: 0 mA to (39 mA  $\pm$  3.9 mA)

##### F.2.3.3.1.3 POTS ringing signal

The splitter shall ensure normal operation of a POTS ringing signal, defined below, impressed at TELE and LINE ports of the splitter. The requirements shall be also taken into account at VDSL(HPF) and VDSL( $R_V$ ) ports to protect against an accidental line connection.

Ringing frequency: 15 Hz to 20 Hz

Ringing AC (superimposed on DC): 83 V<sub>rms</sub> Max

DC: 53 V Max



**F.2.3.3.2 AC signal requirement**

The splitter shall ensure normal operation of service line signals defined below.

**F.2.3.3.2.1 POTS signal**

Frequency: 0.2 kHz to 4.0 kHz

Level: +3 dBm Max (600  $\Omega$ )

Howler signal: +36 dBm (600  $\Omega$ ) at 400 Hz

**F.2.3.3.2.2 ISDN signal**

Line baud rate: 320 kBaud

Line code: AMI (Alternate Mark Inversion)

Pulse shape: 6 V<sub>op</sub> (+20% and -10%) (110  $\Omega$ )

50% ( $\pm 10\%$ ) duty rectangular pulse with 2nd order LPF at  $f_c = 640$  kHz

**F.2.3.3.2.3 VDSL signal**

Frequency: 640 kHz to 12 MHz

Level: +20 dBm Max (100  $\Omega$ )

NOTE – The signal level of +20 dBm Max is referred to a regulation in Japan, and is not correspondent to the VDSL PSD specifications defined in F.1.

**F.2.3.4 Resistibility requirement to overvoltages and overcurrents**

The VTU-O-side splitter, which is installed in customer premises, shall be compliant to the requirements and test procedures specified in ITU-T Rec. K.21. The VTU-O-side splitter, which is installed in customer premises or may be installed in a CO, shall be compliant to the requirements and test procedures specified in both ITU-T Recs K.20 and K.21.

Any terminal connecting to ground as a protective means to overvoltages and overcurrents, e.g., a frame ground (FG) or a lightning ground (LG), shall not be equipped with the external splitters shown in Types J1, J1<sub>opt</sub> and J3 in Figure F.1. The external splitter shall be resistive to overvoltages and overcurrents without being connected to any grounds.

**F.2.3.5 Splitter DC requirement****F.2.3.5.1 DC resistance requirement**

The L1-to-L2 DC resistance between L1 and L2 terminals of LPF part of the splitter, at LINE port with TELE port shorted and vice versa, shall be less than or equal to 10  $\Omega$ .

**F.2.3.5.2 DC isolation resistance requirement****F.2.3.5.2.1 Differential mode DC isolation resistance**

The L1-to-L2 DC isolation resistance between L1 and L2 terminals of LPF part of the splitter, at any one port with the other ports opened if they exist, shall be greater than 10 M $\Omega$ .

The L1-to-L2 DC isolation resistance between L1 and L2 terminals of HPF part of the splitter, at any one port with the other ports opened and shorted if they exist, shall be greater than 10 M $\Omega$ .

**F.2.3.5.2.2 Common mode DC isolation resistance**

The DC isolation resistance between any L1 or L2 terminal and the exterior housing of the external splitter with all ports opened shall be greater than or equal to 10 M $\Omega$  for the external splitters shown in Types J1, J1<sub>opt</sub> and J3 in Figure F.1.

NOTE – Equipping FG or LG terminal with the external splitter is not permitted.

The isolation resistance between any L1 or L2 terminal and ground with all ports opened shall be greater than or equal to 10 M $\Omega$  for the VTU-x modems shown in Types J1, J1<sub>opt</sub>, J2, and J3 in Figure F.1, where ground may be FG or LG terminal of the modem if it exists, or AC or DC main terminal of the modem.

### **F.2.3.6 Splitter capacitance requirement**

#### **F.2.3.6.1 Differential mode capacitance**

Maximum permissible input capacitances for  $R_V$ , LPF and HPF parts shown in Figure F.1 are specified individually so as to depend on the types of the splitters shown in Figure F.1. The input capacitance for each part shall be as follows: LPF and HPF are two port networks, and the input capacitance is defined as the capacitance between L1 and L2 terminals at any one port with the other port opened.  $R_V$  represents the maximum permissible input capacitance of the transceiver function in VTU-x modem. The  $C_{OPT}$  of 0.12  $\mu$ F in Type J1<sub>opt</sub> in Figure F.1 is excluded in the following specific values:

- LPF part: 50 nF Max (DC to 30 Hz);
- HPF part: 40 nF Max (DC to 30 Hz);
- $R_V$  part: 35 nF Max (DC to 30 Hz).

Maximum permissible input capacitances for each type shown in Figure F.1 are described in the following clauses.

##### **F.2.3.6.1.1 Type J1**

- External LPF splitter:

The L1-to-L2 capacitance between L1 and L2 terminals, at LINE port with TELE port opened and vice versa, shall be less than or equal to 50 nF which corresponds to LPF part of 50 nF.

- VTU-x modem with HPF function of the splitter:

The L1-to-L2 capacitance between L1 and L2 terminals at LINE port shall be less than or equal to 75 nF which is the sum of the HPF part of 40 nF and  $R_V$  part of 35 nF.

##### **F.2.3.6.1.2 Type J1<sub>opt</sub>**

- External LPF splitter:

The L1-to-L2 capacitance between L1 and L2 terminals with VDSL(HPF) port opened, at LINE port with TELE port opened and vice versa, shall be less than or equal to 50 nF which corresponds to LPF part of 50 nF.

- VTU-x modem with HPF function of the splitter:

The L1-to-L2 capacitance between L1 and L2 terminals at VDSL(HPF) port shall be less than or equal to 75 nF which is the sum of the HPF part of 40 nF and  $R_V$  part of 35 nF.

NOTE – The input capacitance becomes 33 nF ( $= 75/(120/2)$  nF), when including the  $C_{OPT}$  of 0.12  $\mu$ F.

##### **F.2.3.6.1.3 Type J2**

- VTU-x modem with LPF and HPF functions of the splitter:

The L1-to-L2 capacitance between L1 and L2 terminals, at LINE port with TELE port opened and vice versa, shall be less than or equal to 125 nF which is the sum of LPF part of 50 nF and HPF part of 40 nF and  $R_V$  part of 35 nF.



**F.2.3.6.1.4 Type J3**

- Full external LPF and HPF splitter:  
The L1-to-L2 capacitance between L1 and L2 terminals, at any one port with the other ports opened, shall be less than or equal to 90 nF which is the sum of LPF part of 50 nF and HPF part of 40 nF.
- VTU-x modem without LPF and HPF functions of the splitter:  
The L1-to-L2 capacitance between L1 and L2 terminals at VDSL( $R_V$ ) port shall be less than or equal to 35 nF which correspond to  $R_V$  part of 35 nF.

**F.2.3.6.2 Common mode capacitance**

The capacitance between any L1 or L2 terminal and the exterior housing of the external splitter with all ports opened shall be less than or equal to 1.0 nF for the external splitters shown in Types J1, J1<sub>opt</sub> and J3 in Figure F.1.

NOTE – Equipping FG or LG terminal with the external splitter is not permitted.

The capacitance between any L1 or L2 terminal and ground with all ports opened shall be less than or equal to 1.0 nF for the VTU-x modems shown in Types J1, J1<sub>opt</sub>, J2, and J3 in Figure F.1, where ground may be FG or LG terminal of the modem if it exists, or AC or DC main terminal of the modem.

**F.2.3.7 Splitter AC characteristics requirement**

The requirements for AC characteristics of LPF and HPF parts of the splitter are specified in this clause. LPF and HPF are normally connected to the same wire-pair end, and this causes the mutual effect described below.

LPF signal path characteristics are affected by HPF behaving as a load, where voice and ISDN signals pass through LPF. This degradation by HPF is called HPF loading effect hereafter. Vice versa, HPF signal path characteristics are affected by LPF behaving as a load, where VDSL signal passes through HPF. This degradation by LPF is called LPF loading effect hereafter.

Therefore, the requirements for LPF signal path characteristics shall be met with and without HPF loading and vice versa, the requirement for HPF signal path characteristics shall be met with and without LPF loading.

The associate test methods for splitter AC characteristics are specified in F.2.3.8.

**F.2.3.7.1 Requirement for LPF signal path characteristics and LPF loading effect**

The requirements for AC characteristics of LPF part of the splitter are specified in this clause. The requirements are specified in terms of LPF signal path characteristics and LPF loading effect. As for LPF loading effect on VDSL signal path, discrete LPF loading effect without connecting HPF is specified in this clause. LPF loading effect on VDSL signal path with connecting HPF is specified in F.2.3.7.2.

**F.2.3.7.1.1 LPF insertion loss requirement**

The insertion loss of LPF part of the splitter, which is denoted below as  $LS(f)$  dB at  $f$  kHz, shall be as follows.

- 1) Voiceband (LPF signal path characteristics with and without HPF loading)

$$f = 1.0 \text{ kHz:} \quad -1.0 \text{ dB} \leq LS(1 \text{ kHz}) \leq +1.0 \text{ dB}$$

$$0.2 \text{ kHz} \leq f \leq 3.4 \text{ kHz:} \quad -1.0 \text{ dB} \leq \{LS(f) - LS(1 \text{ kHz})\} \leq +1.0 \text{ dB}$$

$$3.4 \text{ kHz} < f \leq 4.0 \text{ kHz:} \quad -1.5 \text{ dB} \leq \{LS(f) - LS(1 \text{ kHz})\} \leq +1.5 \text{ dB}$$

NOTE 1 –  $\{LS(f) - LS(1 \text{ kHz})\}$  denotes the insertion loss variation in dB at  $f$  kHz from that at 1 kHz.



- 2) ISDN band (LPF signal path characteristics with and without HPF loading)
  - 4.0 kHz <  $f \leq 160$  kHz:  $LS(f) \leq 1.0$  dB
  - 160 kHz <  $f \leq 320$  kHz:  $LS(f) \leq \{1.0 + 3.01 \times \log_2 (f/160)\}$  dB (where  $f$  in kHz)
- 3) Guardband
  - 320 kHz <  $f < 640$  kHz: Not specified

NOTE 2 – The suggested requirements in the guardband is  $42.14 \times \log_2 (f/320)$  dB  $\leq LS(f)$  (where  $f$  in kHz), in order to suppress the TCM-ISDN transmit signal alias leakage, especially at the frequency of 480 kHz, into the VDSL receiver.
- 4) VDSL band (LPF signal path characteristics with HPF loading)
  - 640 kHz  $\leq f < 932$  kHz:  $42.14 \times \log_2 (f/320)$  dB  $\leq LS(f)$  (where  $f$  in kHz)
  - 932 kHz  $\leq f \leq 6.0$  MHz:  $65.0$  dB  $\leq LS(f)$
  - 6.0 MHz <  $f \leq 12$  MHz:  $55.0$  dB  $\leq LS(f)$

#### F.2.3.7.1.2 LPF absolute group delay requirement

The absolute group delay of LPF part of the splitter, which is denoted below as  $GD(f)$   $\mu$ s at  $f$  kHz, shall be as follows.

- 1) Voiceband (LPF signal path characteristics with and without HPF loading)
  - Min [ $GD(f)$  {0.2 kHz  $\leq f \leq 4.0$  kHz}]  $\leq 150$   $\mu$ s
  - 0.2 kHz  $\leq f < 0.6$  kHz:  $GD(f) - GD(f_x) \leq 250$   $\mu$ s
  - 0.6 kHz  $\leq f \leq 3.2$  kHz:  $GD(f) - GD(f_x) \leq 200$   $\mu$ s
  - 3.2 kHz <  $f \leq 4.0$  kHz:  $GD(f) - GD(f_x) \leq 250$   $\mu$ s

NOTE – Min [ $GD(f)$  {0.2 kHz  $\leq f \leq 4.0$  kHz}] denotes minimum absolute group delay for the frequencies from 0.2 kHz to 4.0 kHz, and the frequency of  $f_x$  kHz is defined as the frequency which appears the minimum absolute group delay.  $GD(f) - GD(f_x)$  denotes the increase in  $\mu$ s at  $f$  kHz from the minimum absolute group delay at  $f_x$  kHz.
- 2) ISDN band (LPF signal path characteristics with and without HPF loading)
  - 4.0 kHz <  $f \leq 160$  kHz:  $GD(f) \leq 3.125$   $\mu$ s
  - 160 kHz <  $f \leq 320$  kHz:  $GD(f) \leq 3.125 \times \{1.0 + 2.0 \times \log_2 (f/160)\}$   $\mu$ s (where  $f$  in kHz)
- 3) Guardband
  - 320 kHz <  $f < 640$  kHz: Not specified
- 4) VDSL band
  - 640 kHz  $\leq f \leq 12$  MHz: Not specified

(specified as HPF signal path characteristics with and without LPF loading)

#### F.2.3.7.1.3 LPF return loss requirement

The return loss of LPF part of the splitter, which is denoted below as  $RL(f)$  dB at  $f$  kHz, shall be as follows. The definition of  $RL(f)$  in terms of complex impedances is given below.

$$RL(f) = -20 \times \log_{10}[\text{Abs}\{Z_{\text{ref}}(jf) - Z_{\text{in}}(jf)\} / \{Z_{\text{in}}(jf) + Z_{\text{ref}}(jf)\}] \text{ dB}$$

where  $Z_{\text{in}}(jf)$  is measurements of a complex input impedance and  $Z_{\text{ref}}(jf)$  is the complex reference impedance and  $Z_{\text{ref}}(jf)$  is test band dependent.

- 1) Voiceband (LPF signal path characteristics with and without HPF loading)
  - $0.2 \text{ kHz} \leq f \leq 1.5 \text{ kHz}$ :  $11.0 \text{ dB} \leq \text{RL}(f)$
  - $1.5 \text{ kHz} < f \leq 2.0 \text{ kHz}$ :  $10.0 \text{ dB} \leq \text{RL}(f)$
  - $2.0 \text{ kHz} < f \leq 3.4 \text{ kHz}$ :  $9.0 \text{ dB} \leq \text{RL}(f)$
  - $3.4 \text{ kHz} < f \leq 4.0 \text{ kHz}$ : Not specified
- 2) ISDN band (LPF signal path characteristics with and without HPF loading)
  - $4.0 \text{ kHz} < f < 10 \text{ kHz}$ :  $\{15.0 - 6.02 \times \text{Log}_2(10/f)\} \text{ dB} \leq \text{RL}(f)$  (where  $f$  in kHz)
  - $10 \text{ kHz} \leq f \leq 160 \text{ kHz}$ :  $15.0 \text{ dB} \leq \text{RL}(f)$
  - $160 \text{ kHz} < f \leq 220 \text{ kHz}$ :  $\{15.0 - 6.02 \times \text{Log}_2(f/160)\} \text{ dB} \leq \text{RL}(f)$  (where  $f$  in kHz)
  - $220 \text{ kHz} < f \leq 320 \text{ kHz}$ : Not specified
- 3) Guardband
  - $320 \text{ kHz} < f < 640 \text{ kHz}$ : Not specified
- 4) VDSL band (LPF loading effect on HPF signal path characteristics)
  - $640 \text{ kHz} \leq f < 1.28 \text{ MHz}$ :  $\{12.0 - 6.02 \times \text{Log}_2(1280/f)\} \leq \text{RL}(f)$  (where  $f$  in kHz)
  - $1.28 \text{ MHz} \leq f \leq 12 \text{ MHz}$ :  $12.0 \text{ dB} \leq \text{RL}(f)$

#### F.2.3.7.1.4 LPF longitudinal balance requirement

The longitudinal balance of LPF part of the splitter, which is denoted below as  $\text{LB}(f)$  dB at  $f$  kHz, shall be as follows. The definition of  $\text{LB}(f)$  is given below.

$$\text{LB}(f) = -20 \times \text{Log}_{10} \{V_m(f)/V_t(f)\} \text{ dB}$$

where  $V_t(f)$  is a voltage imposed in common mode from a constant voltage source and in  $V_{emf}$  (electromotive force) which is an output voltage with an open load.  $V_m(f)$  is voltage measurements in differential mode which is converted from common mode to differential mode.

- 1) Voiceband (LPF signal path characteristics with and without HPF loading)
  - $0.2 \text{ kHz} \leq f \leq 3.4 \text{ kHz}$ :  $58.0 \text{ dB} \leq \text{LB}(f)$
  - $3.4 \text{ kHz} < f \leq 4.0 \text{ kHz}$ : Not specified
- 2) ISDN band (LPF signal path characteristics with and without HPF loading)
  - $50 \text{ Hz} \leq f < 150 \text{ kHz}$ :  $60.0 \text{ dB} \leq \text{LB}(f)$
  - $150 \text{ kHz} \leq f \leq 250 \text{ kHz}$ :  $63.0 \text{ dB} \leq \text{LB}(f)$
  - $250 \text{ kHz} < f \leq 320 \text{ kHz}$ :  $\{63.0 - 6.02 \times \text{Log}_2(f/250)\} \text{ dB} \leq \text{LB}(f)$
- 3) Guardband
  - $320 \text{ kHz} < f < 640 \text{ kHz}$ : Not specified
- 4) VDSL band (LPF loading effect on HPF signal path characteristics)
  - $640 \text{ kHz} \leq f \leq 12 \text{ MHz}$ :  $46.0 \text{ dB} \leq \text{LB}(f)$

#### F.2.3.7.2 Requirement for HPF signal path characteristics and HPF loading effect

The requirements for AC characteristics of HPF part of the splitter are specified in this clause. The requirements are specified in terms of HPF signal path characteristics and HPF loading effect. As for HPF loading effect on voice and ISDN signal paths, discrete HPF loading effect without connecting LPF is specified in this clause. HPF loading effect on voice and ISDN signal paths with connecting LPF is specified in F.2.3.7.1.



**F.2.3.7.2.1 HPF insertion loss requirement**

The insertion loss of HPF part of the splitter, which is denoted below as  $LS(f)$  dB at  $f$  kHz, shall be as follows.

- 1) Voiceband (HPF signal path characteristics with LPF loading)  
 $0.2 \text{ kHz} \leq f \leq 4.0 \text{ kHz}$ :  $50.0 \text{ dB} \leq LS(f)$
- 2) ISDN band (HPF signal path characteristics with LPF loading)  
 $4.0 \text{ kHz} < f < 20 \text{ kHz}$ :  $50.0 \text{ dB} \leq LS(f)$   
 $20 \text{ kHz} \leq f \leq 200 \text{ kHz}$ :  $60.6 \text{ dB} \leq LS(f)$   
 $200 \text{ kHz} < f \leq 320 \text{ kHz}$ :  $36.1 \times \log_2(640/f) \text{ dB} \leq LS(f)$  (where  $f$  in kHz)
- 3) Guardband  
 $320 \text{ kHz} < f < 640 \text{ kHz}$ : Not specified  
 NOTE – The suggested requirements in the guardband is  $36.1 \times \log_2(640/f) \text{ dB} \leq LS(f)$  (where  $f$  in kHz), in order to suppress the TCM-ISDN transmit signal alias leakage, especially at the frequency of 480 kHz, into the VDSL receiver.
- 4) VDSL band (HPF signal path characteristics with and without LPF loading)  
 $640 \text{ kHz} \leq f < 1.28 \text{ MHz}$ :  $LS(f) \leq 4.5 - 3.01 \times \log_2(f/640) \text{ dB}$  (where  $f$  in kHz)  
 $1.28 \text{ MHz} \leq f \leq 12 \text{ MHz}$ :  $LS(f) \leq 1.5 \text{ dB}$

**F.2.3.7.2.2 HPF absolute group delay requirement**

The absolute group delay of HPF part of the splitter, which is denoted below as  $GD(f)$   $\mu\text{s}$  at  $f$  kHz, shall be as follows.

- 1) Voiceband  
 $0.2 \text{ kHz} \leq f \leq 4.0 \text{ kHz}$ : Not specified  
 (specified as LPF signal path characteristics with and without HPF loading)
- 2) ISDN band  
 $4.0 \text{ kHz} < f \leq 320 \text{ kHz}$ : Not specified  
 (specified as LPF signal path characteristics with and without HPF loading)
- 3) Guardband  
 $320 \text{ kHz} < f < 640 \text{ kHz}$ : Not specified
- 4) VDSL band (HPF signal path characteristics with and without LPF loading)  
 $640 \text{ kHz} \leq f < 1.28 \text{ MHz}$ :  $GD(f) \leq 1.0 \times \{3.0 - 2.01 \times \log_2(f/640)\} \mu\text{s}$  (where  $f$  in kHz)  
 $1.28 \text{ MHz} \leq f \leq 12 \text{ MHz}$ :  $GD(f) \leq 1.0 \mu\text{s}$

**F.2.3.7.2.3 HPF return loss requirement**

The return loss of HPF part of the splitter, which is denoted below as  $RL(f)$  dB at  $f$  kHz, shall be as follows. The definition of  $RL(f)$  in terms of complex impedances is given below.

$$RL(f) = -20 \times \log_{10}[\text{Abs}\{\{Z_{\text{ref}}(jf) - Z_{\text{in}}(jf)\} / \{(Z_{\text{in}}(jf) + Z_{\text{ref}}(jf))\}] \text{ dB}$$

where  $Z_{\text{in}}(jf)$  is measurements of a complex input impedance and  $Z_{\text{ref}}(jf)$  is the complex reference impedance.

- 1) Voiceband (HPF loading effect on LPF signal path characteristics)
  - $0.2 \text{ kHz} \leq f \leq 1.5 \text{ kHz}$ :  $11.0 \text{ dB} \leq \text{RL}(f)$
  - $1.5 \text{ kHz} < f \leq 2.0 \text{ kHz}$ :  $10.0 \text{ dB} \leq \text{RL}(f)$
  - $2.0 \text{ kHz} < f \leq 3.4 \text{ kHz}$ :  $9.0 \text{ dB} \leq \text{RL}(f)$
  - $3.4 \text{ kHz} < f \leq 4.0 \text{ kHz}$ : Not specified
- 2) ISDN band (HPF loading effect on LPF signal path characteristics)
  - $4.0 \text{ kHz} < f < 10 \text{ kHz}$ :  $\{15.0 - 6.02 \times \text{Log}_2(10/f)\} \text{ dB} \leq \text{RL}(f)$  (where  $f$  in kHz)
  - $10 \text{ kHz} \leq f \leq 160 \text{ kHz}$ :  $15.0 \text{ dB} \leq \text{RL}(f)$
  - $160 \text{ kHz} < f \leq 220 \text{ kHz}$ :  $\{15.0 - 6.02 \times \text{Log}_2(f/160)\} \text{ dB} \leq \text{RL}(f)$  (where  $f$  in kHz)
  - $220 \text{ kHz} < f \leq 320 \text{ kHz}$ : Not specified
- 3) Guardband
  - $320 \text{ kHz} < f < 640 \text{ kHz}$ : Not specified
- 4) VDSL band (HPF signal path characteristics with and without LPF loading)
  - $640 \text{ kHz} \leq f < 1.28 \text{ MHz}$ :  $\{12.0 - 6.02 \times \text{Log}_2(1280/f)\} \leq \text{RL}(f)$  (where  $f$  in kHz)
  - $1.28 \text{ MHz} \leq f \leq 12 \text{ MHz}$ :  $12.0 \text{ dB} \leq \text{RL}(f)$

#### F.2.3.7.2.4 HPF longitudinal balance requirement

The longitudinal balance of HPF part of the splitter, which is denoted below as  $\text{LB}(f)$  dB at  $f$  kHz, shall be as follows. The definition of  $\text{LB}(f)$  is given below.

$$\text{LB}(f) = -20 \times \text{Log}_{10} \{V_m(f)/V_t(f)\} \text{ dB}$$

where  $V_t(f)$  is a voltage imposed in common mode from a constant voltage source and in  $V_{emf}$  (electromotive force) which is an output voltage with an open load.  $V_m(f)$  is voltage measurements in differential mode which is converted from common mode to differential mode.

- 1) Voiceband (HPF loading effect on LPF signal path characteristics)
  - $0.2 \text{ kHz} \leq f \leq 3.4 \text{ kHz}$ :  $64.0 \text{ dB} \leq \text{LB}(f)$
  - $3.4 \text{ kHz} < f \leq 4.0 \text{ kHz}$ : Not specified
- 2) ISDN band (HPF loading effect on LPF signal path characteristics)
  - $50 \text{ Hz} \leq f < 150 \text{ kHz}$ :  $66.0 \text{ dB} \leq \text{LB}(f)$
  - $150 \text{ kHz} \leq f \leq 250 \text{ kHz}$ :  $69.0 \text{ dB} \leq \text{LB}(f)$
  - $250 \text{ kHz} < f \leq 320 \text{ kHz}$ :  $\{69.0 - 6.02 \times \text{Log}_2(f/250)\} \text{ dB} \leq \text{LB}(f)$
- 3) Guardband
  - $320 \text{ kHz} < f < 640 \text{ kHz}$ : Not specified
- 4) DSL band (HPF signal path characteristics with and without LPF loading)
  - $640 \text{ kHz} \leq f \leq 12 \text{ MHz}$ :  $40.0 \text{ dB} \leq \text{LB}(f)$

#### F.2.3.8 AC characteristics test method

The test set-up configurations and the test conditions regarding splitter AC characteristics are specified in this clause. The test set-up configurations shown in this clause enable to test LPF and HPF parts of the splitter independently of the types of the splitters shown in Figure F.1.

The test methods for LPF signal path characteristics with and without HPF loading and discrete LPF loading effect without connecting HPF are specified in F.2.3.8.1.



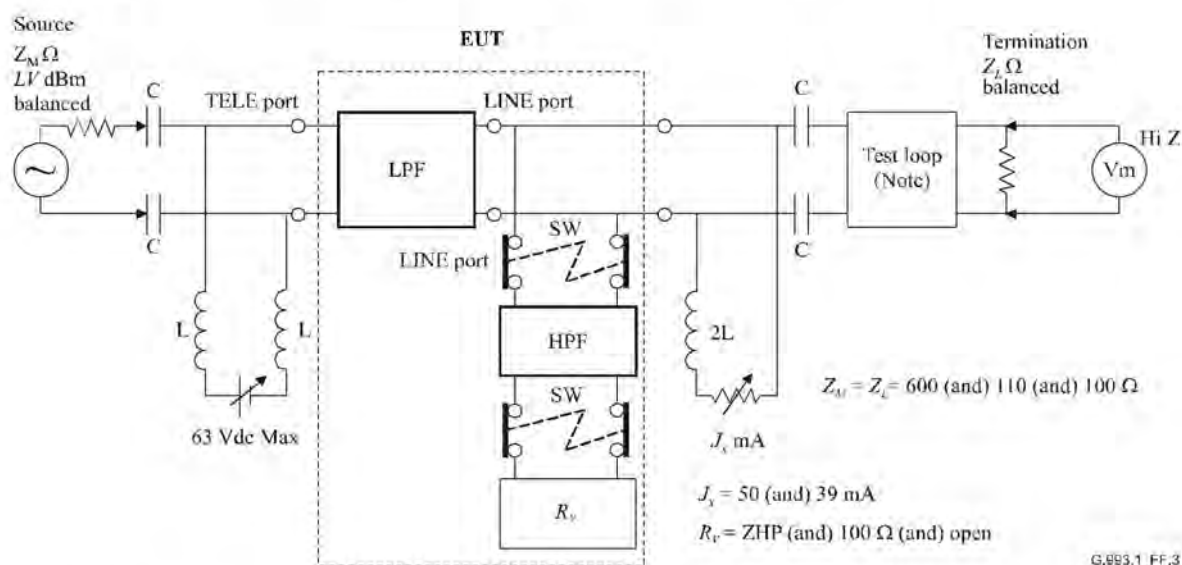
The test methods for HPF signal path characteristics with and without LPF and discrete HPF loading effect without connecting LPF are specified in F.2.3.8.2.

#### F.2.3.8.1 Test method for LPF signal path characteristics and LPF loading effect

The test set-up configurations and the test conditions regarding splitter AC characteristics for LPF part of the splitter are specified in this clause. The requirements which shall be met in test below are specified in F.2.3.7.1

##### F.2.3.8.1.1 LPF insertion loss and absolute group delay test

The test set-up is shown in Figure F.3. The insertion loss and group delay from the source of  $Z_M \Omega$  to the termination of  $Z_L \Omega$  shall be measured, with and without inserting the equipment under test (EUT), with a level of LV dBm under the all conditions of HPF loading. The test loop in the figure is used only for voiceband test and defined in Figure F.4. Null loop is applied for ISDN and VDSL band test.



NOTE – Test loop is used only for voice band test. Null loop is applied for ISDN and VDSL band test.

Figure F.3/G.993.1 – Test set-up for LPF insertion loss and absolute group delay

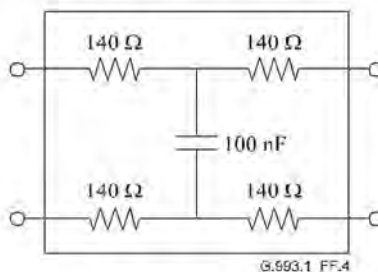


Figure F.4/G.993.1 – Voiceband test loop (approx. 2 km)

All possible conditions are defined as for HPF loading although the conditions of HPF loading are dependent on the types of the splitters shown in Figure F.1. Thus, the conditions defined below may include inapplicable cases which are unable to test for a certain type of actual implementation. Even



in those types, LPF as part of the splitter shall meet all requirements under the all conditions defined below.

A DC bias current of  $J_x$  mA to LPF part of the splitter shall be applied during the test. The C and L in Figure F.3 are for superimposing the DC bias current of  $J_x$  mA. Proper values of the C and L should be set for testing each band.

$LV$  dBm,  $Z_M$   $\Omega$ ,  $Z_L$   $\Omega$ ,  $J_x$  mA, and the conditions of HPF loading are test band dependent and shall be as follows:

- 1) Voiceband ( $0.2 \text{ kHz} \leq f \leq 4.0 \text{ kHz}$ )
  - $LV = 0 \text{ dBm}$
  - $Z_M = Z_L = 600 \Omega$
  - $J_x = 50 \text{ mA}$  (e.g.,  $C \geq 20 \mu\text{F}$  and  $L \geq 15 \text{ H}$ )
    - a1) Connecting HPF terminated with  $R_V = \text{ZHP}$  (defined in Figure F.2) to the line
    - a2) Connecting HPF terminated with  $R_V = \text{open}$  to the line
    - b) Unconnecting HPF terminated with  $R_V$  to the line
- 2) ISDN band ( $4.0 \text{ kHz} < f \leq 320 \text{ kHz}$ )
  - $LV = +15 \text{ dBm}$
  - $Z_M = Z_L = 110 \Omega$
  - $J_x = 39 \text{ mA}$  (e.g.,  $C \geq 10 \mu\text{F}$  and  $L \geq 0.5 \text{ H}$ )
    - a1) Connecting HPF terminated with  $R_V = \text{ZHP}$  (defined in Figure F.2) to the line
    - a2) Connecting HPF terminated with  $R_V = \text{open}$  to the line
    - b) Unconnecting HPF terminated with  $R_V$  to the line
- 3) Guardband ( $320 \text{ kHz} < f < 640 \text{ kHz}$ )
  - Not specified
- 4) VDSL band ( $640 \text{ kHz} \leq f \leq 12 \text{ MHz}$ ): only for insertion loss, not applied for group delay.
  - $LV = +15 \text{ dBm}$
  - $Z_M = Z_L = 100 \Omega$
  - $J_x = 39 \text{ mA}$  (e.g.,  $C \geq 0.2 \mu\text{F}$  and  $L \geq 5 \text{ mH}$ )
  - Connecting HPF terminated with  $R_V = 100 \Omega$  to the line

#### **F.2.3.8.1.2 LPF return loss test**

The test set-up is shown in Figure F.5. The return loss is measured in terms of a complex input impedance of  $Z_{in}(jf)$ .  $Z_{in}(jf)$  shall be measured with inserting EUT and terminating the opposite side by the complex reference impedance of  $Z_{ref}(jf)$ . Note that the port where  $Z_{in}(jf)$  is measured is opposite each other for voice and ISDN bands. As for VDSL band test, an effect on VDSL signal path is evaluated as discrete LPF loading effect without connecting HPF.

A DC bias current is not necessarily required to apply during the test.

$Z_{ref}(jf)$  and the conditions of HPF and LPF loading are test band dependent, and shall be as follows:

- 1) Voiceband ( $0.2 \text{ kHz} \leq f \leq 4.0 \text{ kHz}$ )  
 $Z_{ref}(jf) = Z_{NLr}$  for testing VTU-R-side splitter and  $Z_{NLc}$  for testing VTU-O-side splitter  
 where  $Z_{NLr} = 150 \, \Omega + \{(830 \, \Omega + 1 \, \mu F) // 72 \, nF\}$   
 $Z_{NLc} = 150 \, \Omega + (830 \, \Omega // 72 \, nF)$   
 (+: series connection   //: parallel connection)  
 NOTE – The definition of  $Z_{NLr}$  and  $Z_{NLc}$  is as per E.4/G.992.3.
  - a1) Connecting HPF terminated with  $R_V = Z_{HP}$  (defined in Figure F.2) to the line
  - a2) Connecting HPF terminated with  $R_V = \text{open}$  to the line
  - b) Unconnecting HPF terminated with  $R_V$  to the line
- 2) ISDN band ( $4.0 \text{ kHz} < f \leq 320 \text{ kHz}$ )  
 $Z_{ref}(jf) = \text{pure resistive } 110 \, \Omega$ 
  - a1) Connecting HPF terminated with  $R_V = Z_{HP}$  (defined in Figure F.2) to the line
  - a2) Connecting HPF terminated with  $R_V = \text{open}$  to the line
  - b) Unconnecting HPF terminated with  $R_V$  to the line
- 3) Guardband ( $320 \text{ kHz} < f < 640 \text{ kHz}$ )  
 Not specified
- 4) VDSL band ( $640 \text{ kHz} \leq f \leq 12 \text{ MHz}$ )  
 $Z_{ref}(jf) = \text{pure resistive } 100 \, \Omega$ 
  - a1) Connecting LPF only in parallel to the line and terminating with  $Z_M = 600 \, \Omega$
  - a2) Connecting LPF only in parallel to the line and terminating with  $Z_M = 110 \, \Omega$
  - a3) Connecting LPF only in parallel to the line and terminating with  $Z_M = \text{open}$

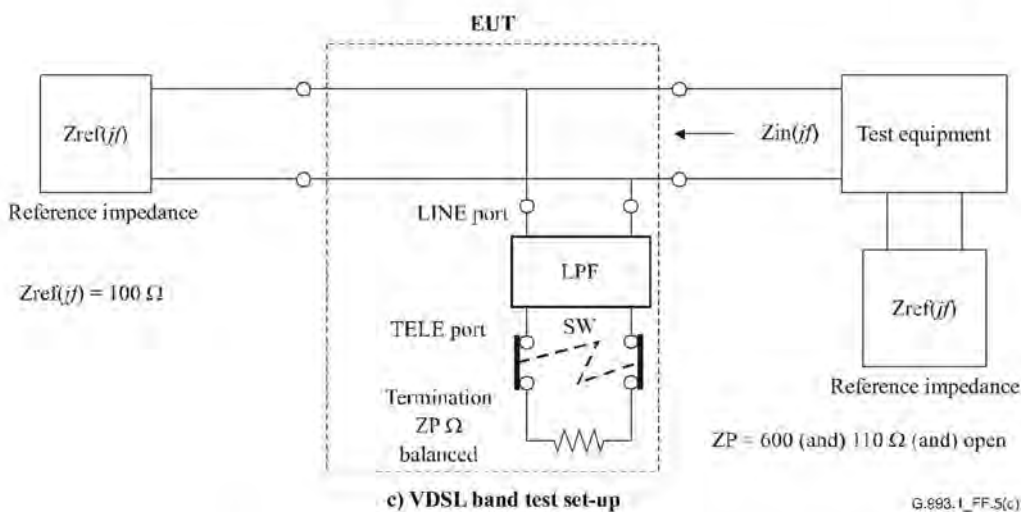
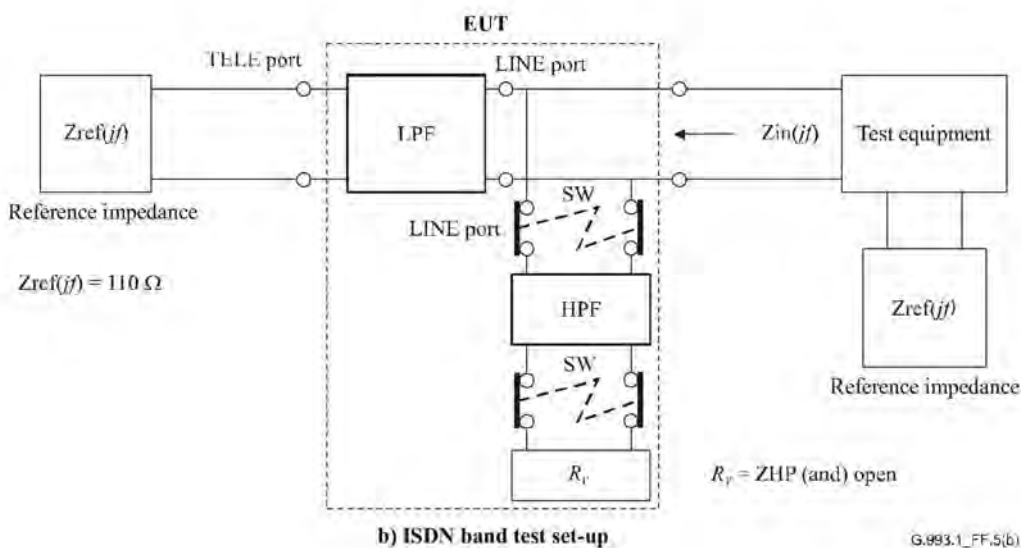
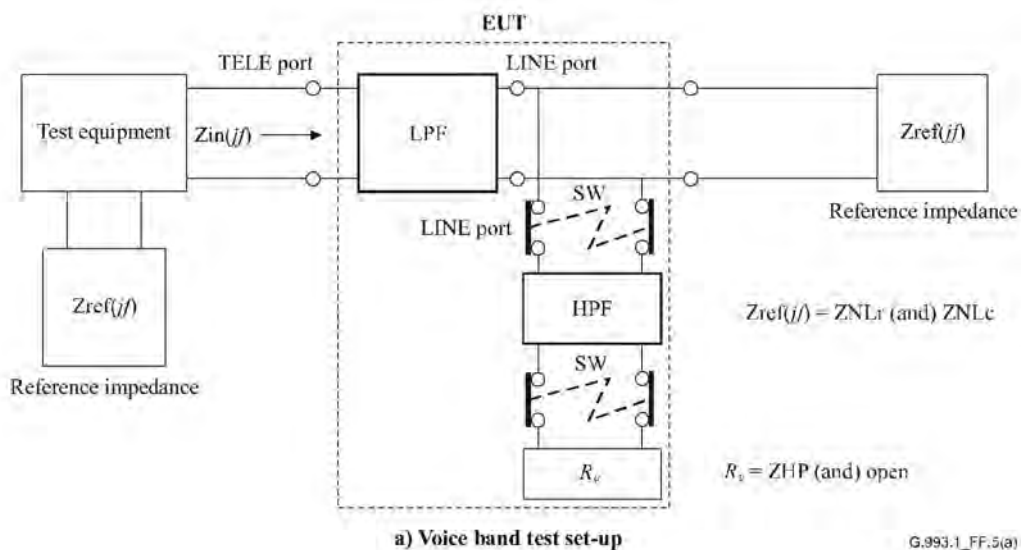
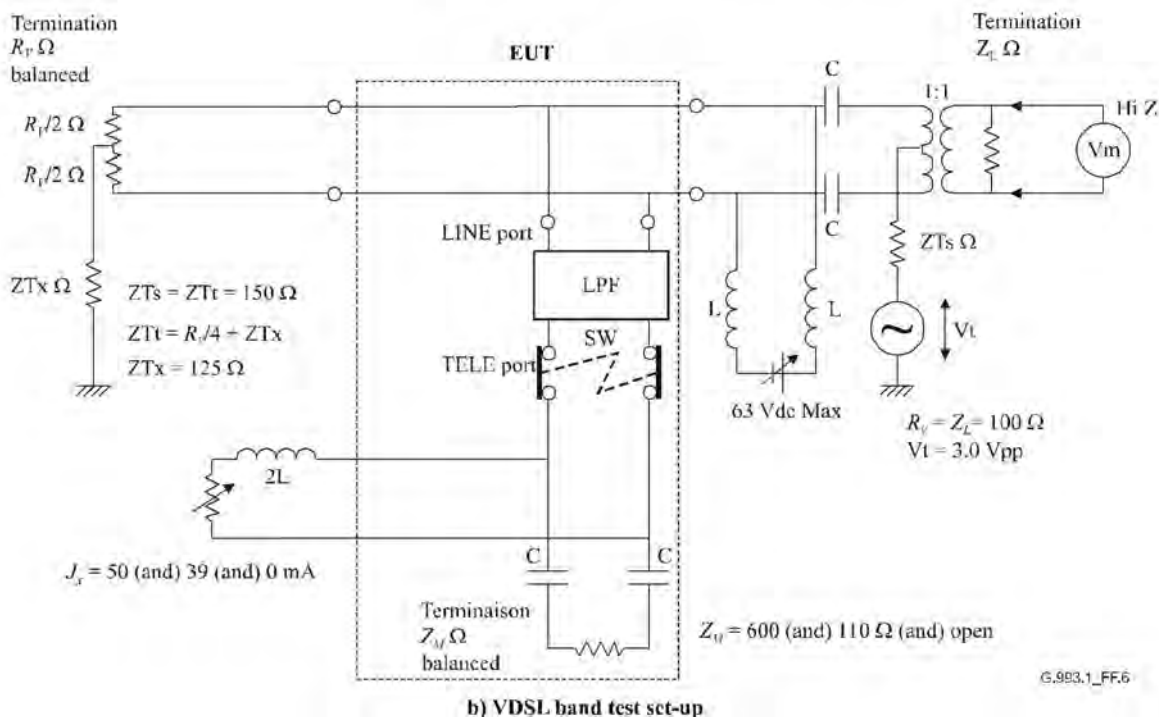
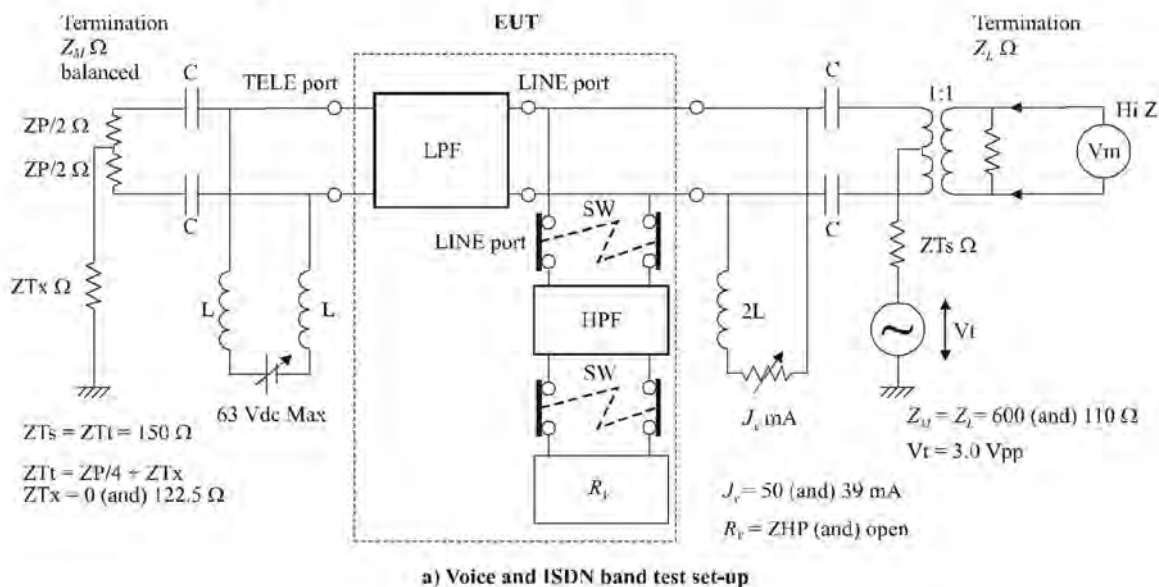


Figure F.5/G.993.1 – Test set-up for LPF return loss

### F.2.3.8.1.3 F longitudinal balance test

The longitudinal balance shall be measured under the all conditions of HPF loading by using the test set-up shown in Figure F.6. As for VDSL band test, an effect on VDSL signal path is evaluated as discrete LPF loading effect without connecting HPF.



**Figure F.6/G.993.1 – Test set-up for LPF longitudinal balance**

The source impedance of  $Z_{Ts} \Omega$  and the terminal impedance of  $Z_{Tt} \Omega$  in common mode are compliant to the requirement specified in ITU-T Rec. K.43, and shall be  $150 \Omega$ , where  $Z_{Ts} = Z_{Tt} (= Z_M/4 + Z_{Tx})$ .



The electromotive force  $V_t(f)$  of the constant voltage source shall be 3.0 Vpp (emf), and this level in  $V_{emf}$  corresponds to the level in dBm of +7.5 dBm for the signal generator with the source of 50  $\Omega$  and the termination of 50  $\Omega$ .

A DC bias current of  $J_x$  mA to LPF part of the splitter shall be applied during the test. Proper values of the C and L in the figure should be set for testing each band.

$Z_M$   $\Omega$ ,  $Z_L$   $\Omega$ ,  $Z_{Tx}$   $\Omega$ ,  $J_x$  mA, and the conditions of HPF and LPF loading are test band dependent, and shall be as follows.

- 1) Voiceband ( $0.2 \text{ kHz} \leq f \leq 4.0 \text{ kHz}$ )
  - $V_t(f) = 3.0 \text{ Vpp (emf)}$
  - $Z_M = Z_L = 600 \text{ } \Omega$
  - $Z_{Tx} = 0 \text{ } \Omega$
  - $J_x = 50 \text{ mA (e.g., } C \geq 20 \text{ } \mu\text{F and } L \geq 15 \text{ H)}$
  - a1) Connecting HPF terminated with  $R_V = Z_{HP}$  (defined in Figure F.2) to the line
  - a2) Connecting HPF terminated with  $R_V = \text{open}$  to the line
  - b) Unconnecting HPF terminated with  $R_V$  to the line
- 2) ISDN band ( $4.0 \text{ kHz} < f \leq 320 \text{ kHz}$ )
  - $V_t(f) = 3.0 \text{ Vpp (emf)}$
  - $Z_M = Z_L = 110 \text{ } \Omega$
  - $Z_{Tx} = 122.5 \text{ } \Omega$
  - $J_x = 39 \text{ mA (e.g., } C \geq 10 \text{ } \mu\text{F and } L \geq 0.5 \text{ H)}$
  - a1) Connecting HPF terminated with  $R_V = Z_{HP}$  (defined in Figure F.2) to the line
  - a2) Connecting HPF terminated with  $R_V = \text{open}$  to the line
  - b) Unconnecting HPF terminated with  $R_V$  to the line
- 3) Guardband ( $320 \text{ kHz} < f < 640 \text{ kHz}$ )
  - Not specified
- 4) VDSL band ( $640 \text{ kHz} \leq f \leq 12 \text{ MHz}$ )
  - $V_t(f) = 3.0 \text{ Vpp (emf)}$
  - $R_V = Z_L = 100 \text{ } \Omega$
  - $Z_{Tx} = 125 \text{ } \Omega$
  - a1) Connecting LPF only in parallel to the line and terminating with  $Z_M = 600 \text{ } \Omega$ 
    - $J_x = 50 \text{ mA (e.g., } C \geq 0.2 \text{ } \mu\text{F and } L \geq 5 \text{ mH)}$
  - a2) Connecting LPF only in parallel to the line and terminating with  $Z_M = 110 \text{ } \Omega$ 
    - $J_x = 39 \text{ mA (e.g., } C \geq 0.2 \text{ } \mu\text{F and } L \geq 5 \text{ mH)}$
  - a3) Connecting LPF only in parallel to the line and terminating with  $Z_M = \text{open}$ 
    - No DC bias current

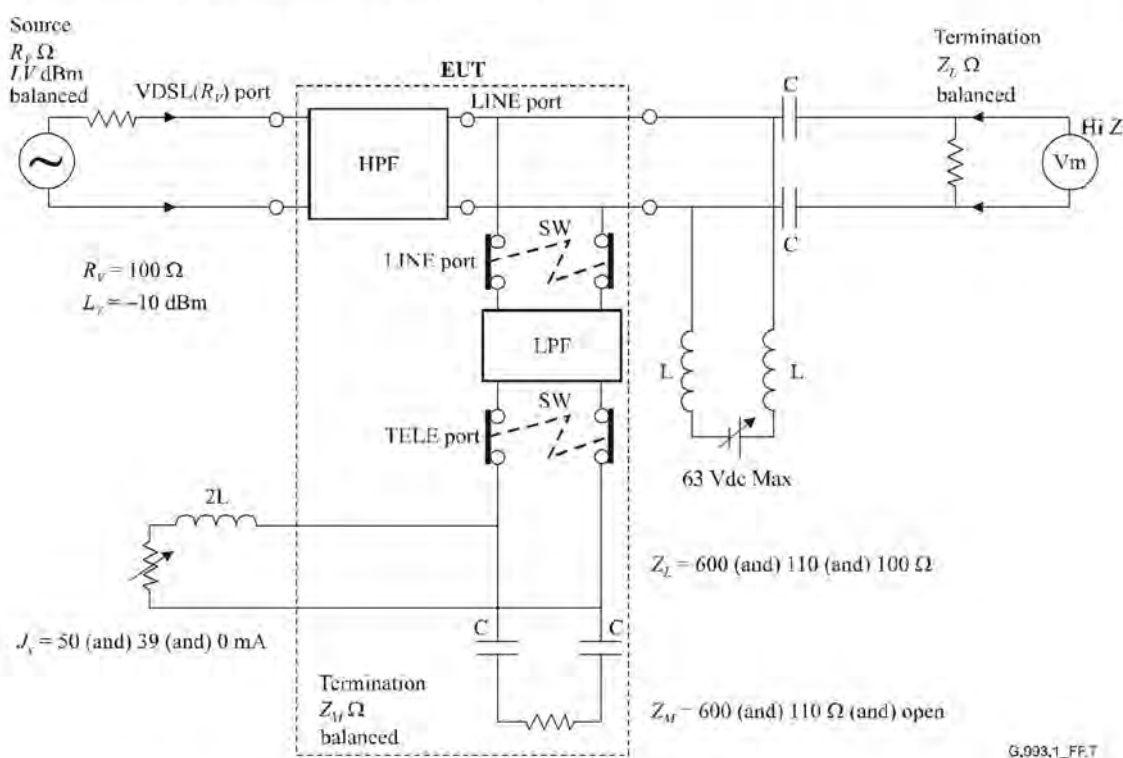
#### **F.2.3.8.2 Test method for HPF signal path characteristics and HPF loading effect**

The test set-up configurations and the test conditions regarding splitter AC characteristics for HPF part of the splitter are specified in this clause. The requirements which shall be met in test below are specified in F.2.3.7.2.



#### F.2.3.8.2.1 HPF insertion loss and absolute group delay test

The test set-up is shown in Figure F.7. The insertion loss and group delay from the source of  $R_V \Omega$  to the termination of  $Z_L \Omega$  shall be measured, with and without inserting EUT, with a level of LV dBm under the all conditions of LPF loading.



**Figure F.7/G.993.1 – Test set-up for HPF insertion loss and absolute group delay**

All possible conditions are defined as for LPF loading although the conditions of LPF loading are dependent on the types of the splitters shown in Figure F.1. Thus, the conditions defined below may include inapplicable cases which are unable to test for a certain type of actual implementation. Even in those types, HPF as part of the splitter shall meet all requirements under the conditions defined below.

A DC bias current of  $J_x$  mA to LPF part of the splitter shall be applied during the test in all available cases. Proper values of the C and L should be set for testing each band.

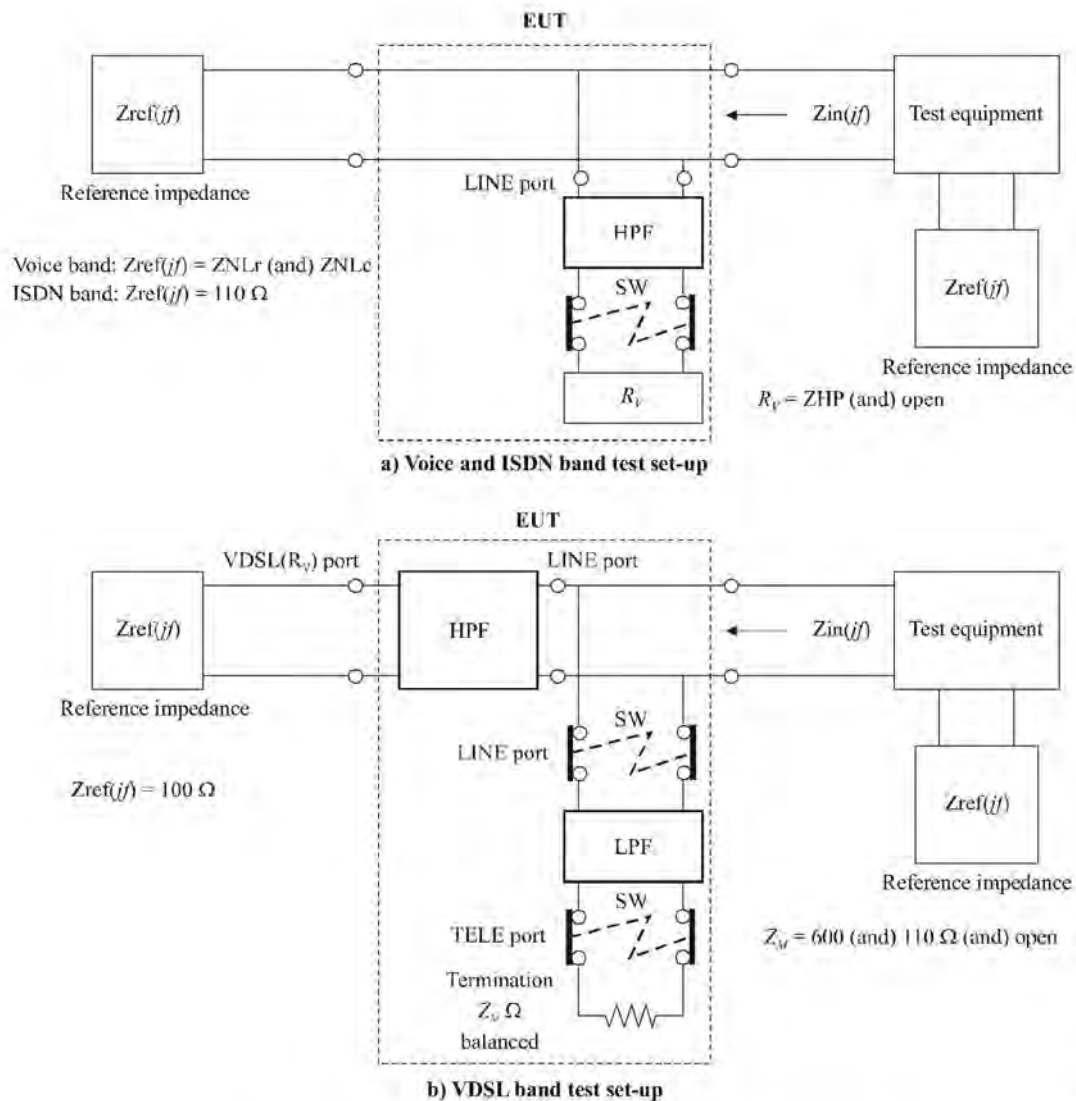
$LV$  dBm,  $R_F$   $\Omega$ ,  $Z_L$   $\Omega$ ,  $J_x$  mA and the conditions of LPF loading shall be as follows, where the  $Z_L$   $\Omega$ ,  $J_x$  mA and conditions of LPF loading are test band dependent.

- 1) Voiceband ( $0.2 \text{ kHz} \leq f \leq 4.0 \text{ kHz}$ ): only for insertion loss, not applied for group delay.  
 $LV = -10 \text{ dBm}$   
 $R_F = 100 \text{ } \Omega$   
 $Z_L = 600 \text{ } \Omega$   
Connecting LPF terminated with  $Z_M = 600 \text{ } \Omega$  to the line  
 $J_N = 50 \text{ mA}$  (e.g.,  $C \geq 20 \text{ } \mu\text{F}$  and  $L \geq 15 \text{ H}$ )

- 2) ISDN band ( $4.0 \text{ kHz} < f \leq 320 \text{ kHz}$ ) : only for insertion loss, not applied for group delay.  
 $LV = -10 \text{ dBm}$   
 $R_V = 100 \ \Omega$   
 $Z_L = 110 \ \Omega$   
 Connecting LPF terminated with  $Z_M = 110 \ \Omega$  to the line  
 $J_x = 39 \text{ mA}$  (e.g.,  $C \geq 10 \ \mu\text{F}$  and  $L \geq 0.5 \text{ H}$ )
- 3) Guardband ( $320 \text{ kHz} < f < 640 \text{ kHz}$ )  
 Not specified
- 4) VDSL band ( $640 \text{ kHz} \leq f \leq 12 \text{ MHz}$ )  
 $LV = -10 \text{ dBm}$   
 $R_V = Z_L = 100 \ \Omega$ 
  - a1) Connecting LPF terminated with  $Z_M = 600 \ \Omega$  to the line  
 $J_x = 50 \text{ mA}$  (e.g.,  $C \geq 0.2 \ \mu\text{F}$  and  $L \geq 5 \text{ mH}$ )
  - a2) Connecting LPF terminated with  $Z_M = 110 \ \Omega$  to the line  
 $J_x = 39 \text{ mA}$  (e.g.,  $C \geq 0.2 \ \mu\text{F}$  and  $L \geq 5 \text{ mH}$ )
  - a3) Connecting LPF terminated with  $Z_M = \text{open}$  to the line  
 No DC bias current
  - b) Unconnecting LPF terminated with  $Z_M$  to the line  
 No DC bias current

#### **F.2.3.8.2.2 HPF return loss test**

The test set-up is shown in Figure F.8. The return loss is measured in terms of a complex input impedance of  $Z_{in}(jf)$ .  $Z_{in}(jf)$  shall be measured with inserting EUT and terminating the opposite side by the complex reference impedance of  $Z_{ref}(jf)$ . As for voice and ISDN band test, effects on voice and ISDN signal paths are evaluated as discrete HPF loading effect without connecting LPF.



**Figure F.8/G.993.1 – Test set-up for HPF return loss**

A DC bias current is not necessarily required to apply during the test.

$Z_{ref}(jf)$  and the conditions of LPF and HPF loading are test band dependent, and shall be as follows.

- 1) Voiceband ( $0.2 \text{ kHz} \leq f \leq 4.0 \text{ kHz}$ )  
 $Z_{\text{ref}}(j\omega) = Z_{\text{NLr}}$  for testing VTU-R-side splitter and  $Z_{\text{NLc}}$  for testing VTU-O-side splitter  
 where  $Z_{\text{NLr}} = 150 \, \Omega + \{(830 \, \Omega + 1 \, \mu\text{F}) // 72 \, \text{nF}\}$   
 $Z_{\text{NLc}} = 150 \, \Omega + (830 \, \Omega // 72 \, \text{nF})$

(+: series connection    //: parallel connection)

NOTE – The definition of ZNLr and ZNLc is as per E.4/G.992.3.

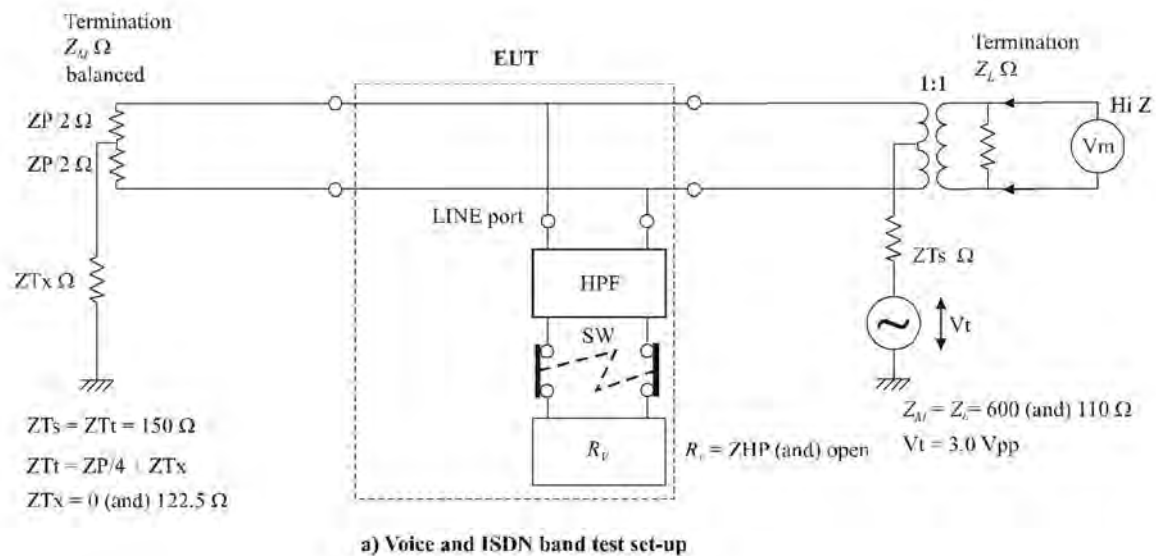
- a1) Connecting HPF only in parallel to the line and terminating with  $R_V = Z_{HP}$  (defined in Figure F.2)
- a2) Connecting HPF only in parallel to the line and terminating with  $R_V = \text{open}$

- 2) ISDN band ( $4.0 \text{ kHz} < f \leq 320 \text{ kHz}$ )  
 $Z_{\text{ref}}(j\omega) = \text{pure resistive } 110 \Omega$ 
  - a1) Connecting HPF only in parallel to the line and terminating with  $R_V = Z_{\text{HP}}$  (defined in Figure F.2)
  - a2) Connecting HPF only in parallel to the line and terminating with  $R_V = \text{open}$
- 3) Guardband ( $320 \text{ kHz} < f < 640 \text{ kHz}$ )  
 Not specified
- 4) VDSL band ( $640 \text{ kHz} \leq f \leq 12 \text{ MHz}$ )  
 $Z_{\text{ref}}(j\omega) = \text{pure resistive } 100 \Omega$ 
  - a1) Connecting LPF terminated with  $Z_M = 600 \Omega$  to the line
  - a2) Connecting LPF terminated with  $Z_M = 110 \Omega$  to the line
  - a3) Connecting LPF terminated with  $Z_M = \text{open}$  to the line
  - b) Unconnecting LPF terminated with  $Z_M$  to the line

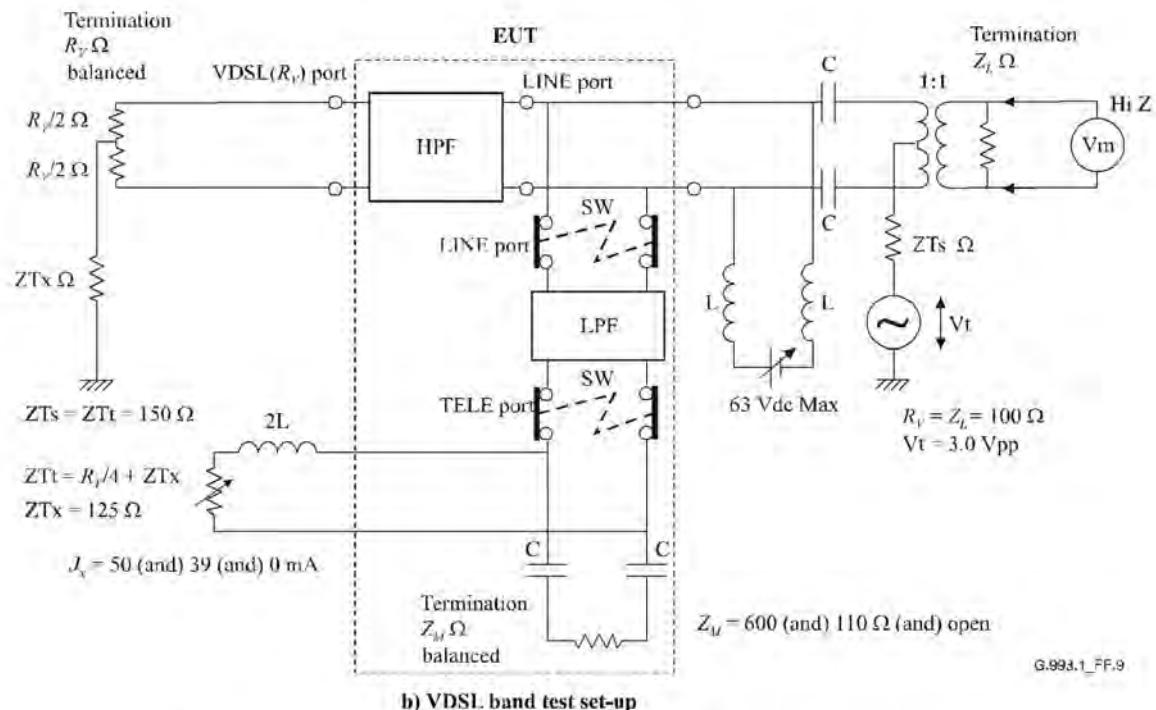
#### **F.2.3.8.2.3 HPF longitudinal balance test**

The longitudinal balance shall be measured under the all conditions of LPF loading by using the test set-up shown in Figure F.9. As for voice and ISDN band test, effects on voice and ISDN signal paths are evaluated as discrete HPF loading effect without connecting LPF.





#### a) Voice and ISDN band test set-up



### b) VDSL band test set-up

**Figure F.9/G.993.1 – Test set-up for HPF longitudinal balance**

The source impedance of ZTs  $\Omega$  and the terminal impedance of ZTt  $\Omega$  in common mode comply with the requirement specified in ITU-T Rec. K.43, and shall be 150  $\Omega$ , where  $ZTs = ZTt (= R_V/4 + ZTx)$ .

The electromotive force  $V_t(f)$  of the constant voltage source shall be 3.0 V<sub>pp</sub> (emf), and this level in  $V_{emf}$  corresponds to the level in dBm of +7.5 dBm for the signal generator with the source of 50  $\Omega$  and the termination of 50  $\Omega$ .

A DC bias current of  $J_x$  mA to LPF part of the splitter shall be applied during the test in all available cases. Proper values of the C and L should be set for testing each band.



$Z_M$   $\Omega$ ,  $Z_L$   $\Omega$ ,  $Z_{Tx}$   $\Omega$ ,  $J_x$  mA and the conditions of LPF and HPF loading are test band dependent, and shall be as follows:

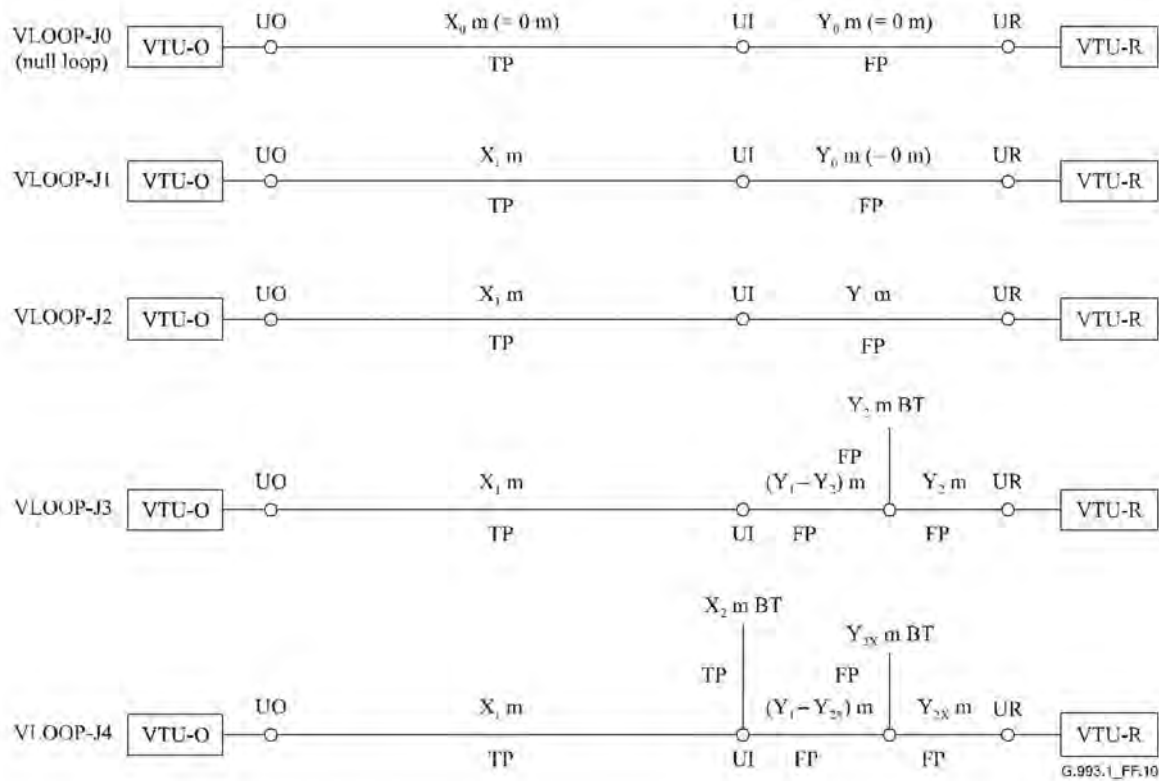
- 1) Voiceband ( $0.2 \text{ kHz} \leq f \leq 4.0 \text{ kHz}$ )
  - $V_t(f) = 3.0 \text{ Vpp (cmf)}$
  - $Z_M = Z_L = 600 \Omega$
  - $Z_{Tx} = 0 \Omega$
  - a1) Connecting HPF only in parallel to the line and terminating with  $R_V = Z_{HP}$  (defined in Figure F.2)
    - No DC bias current
  - a2) Connecting HPF only in parallel to the line and terminating with  $R_V = \text{open}$ 
    - No DC bias current
- 2) ISDN band ( $4.0 \text{ kHz} < f \leq 320 \text{ kHz}$ )
  - $V_t(f) = 3.0 \text{ Vpp (cmf)}$
  - $Z_M = Z_L = 110 \Omega$
  - $Z_{Tx} = 122.5 \Omega$
  - a1) Connecting HPF only in parallel to the line and terminating with  $R_V = Z_{HP}$  (defined in Figure F.2)
    - No DC bias current
  - a2) Connecting HPF only in parallel to the line and terminating with  $R_V = \text{open}$ 
    - No DC bias current
- 3) Guardband ( $320 \text{ kHz} < f < 640 \text{ kHz}$ )
  - Not specified
- 4) VDSL band ( $640 \text{ kHz} \leq f \leq 12 \text{ MHz}$ )
  - $V_t(f) = 3.0 \text{ Vpp (cmf)}$
  - $R_V = Z_L = 100 \Omega$
  - $Z_{Tx} = 125 \Omega$
  - a1) Connecting LPF terminated with  $Z_M = 600 \Omega$  to the line
    - $J_x = 50 \text{ mA}$  (e.g.,  $C \geq 0.2 \mu\text{F}$  and  $L \geq 5 \text{ mH}$ )
  - a2) Connecting LPF terminated with  $Z_M = 110 \Omega$  to the line
    - $J_x = 39 \text{ mA}$  (e.g.,  $C \geq 0.2 \mu\text{F}$  and  $L \geq 5 \text{ mH}$ )
  - a3) Connecting LPF terminated with  $Z_M = \text{open}$  to the line
    - No DC bias current
  - b) Unconnecting LPF terminated with  $Z_M$  to the line
    - No DC bias current

### **F.3 Test loops and crosstalk disturbers**

#### **F.3.1 Test loops**

##### **F.3.1.1 Loop configurations**

The test loops specified in Figure F.10 shall be used to test the transmission performance of VDSL.



**Figure F.10/G.993.1 – VDSL test loops for environment co-existing with TCM-ISDN DSL**

- 1) Two kinds of wire pairs abbreviated by TP and FP in Figure F.10 are as follows:  
 TP: 0.4 mm PE cable – Polyethylene insulated and quad configuration multi-pair cable  
 FP: 0.5 mm PVC FP – Polyvinyl chloride insulated and flat untwisted single pair
- 2) The nominal values of  $X_j$  ( $j = 0$  to  $2$ ) and  $Y_j$  ( $j = 0$  to  $2$ ) marked in Figure F.10 as adjustable-length sections are as follows. The lengths of TP range from 0 to 1500 m and the lengths of FP are 0 m and 50 m. A bridged tap (BT) is an unterminated open-ended and branched section.  
 $X_0 = 0$  m  
 $X_1 = 300, 500, 1000, 1200, 1500$  m  
 $X_2 = 25, 50$  m  
 $Y_0 = 0$  m  
 $Y_1 = 50$  m  
 $Y_2 = 5$  to  $50$  m at every 5-m step  
 $Y_{2DS}$ : The most significant length for downstream transmission performance  
 $Y_{2US}$ : The most significant length for upstream transmission performance  
 $Y_{2X} = Y_{2DS}$  for downstream performance test and  $Y_{2US}$  for upstream performance test

### F.3.1.2 Primary line constants

The primary line constants are  $R$ ,  $L$ ,  $C$ , and  $G$ . The equations below give the values of  $R$  in ohm/m,  $L$  in H/m,  $G$  in mho/m,  $C$  in F/m, and  $f$  (frequency) in Hz. The coefficient values are shown in Table F.5.

$$R = 2(Ri + Rn + Rns) \quad [\text{ohm/m}]$$

$$L = 2(La + Li + Ln + Lns) \quad [\text{H/m}]$$

$$C = C_i + \frac{C_{0,d}}{(f+1)^{ce}} \quad [\text{F/m}]$$

$$G = 2\pi f^{ge} C \tan \delta \quad [\text{mho/m}]$$

$$Ri = \frac{1}{\pi r_i^2 \sigma_i} \text{Re} \left[ \frac{\lambda}{2} \frac{J_0(\lambda)}{J_1(\lambda)} \right] : \text{skin effect}$$

$$Rn = \frac{1}{\pi d_i^2 \sigma_i} \text{Re} \left[ -\lambda \frac{J_1(\lambda)}{J_0(\lambda)} \right] : \text{intra-pair eddy current effect}$$

$$Rns = \frac{1}{\pi d_i^2 \sigma_i} 4 \text{Re} \left[ -\lambda \frac{J_1(\lambda)}{J_0(\lambda)} \right] : \text{intra-quad eddy current effect (in case of 0.4 mm PE)}$$

$$Rns = 0 : \text{intra-quad eddy current effect (in case of 0.5 mm PVC FP)}$$

$$La = \frac{\mu_0}{2\pi} \ln \left( \frac{d_i}{r_i} \right) : \text{external inductance}$$

$$Li = \frac{\mu_i}{2\pi} \text{Re} \left[ -\frac{1}{\lambda} \frac{J_0(\lambda)}{J_1(\lambda)} \right] : \text{skin effect}$$

$$Ln = -\frac{\mu_0}{2\pi} \left( \frac{r_i}{d_i} \right)^2 \text{Re} \left[ -\frac{J_2(\lambda)}{J_0(\lambda)} \right] : \text{intra-pair eddy current effect}$$

$$Lns = -\frac{\mu_0}{2\pi} \left( \frac{r_i}{d_i} \right)^2 4 \text{Re} \left[ -\frac{J_2(\lambda)}{J_0(\lambda)} \right] : \text{intra-quad eddy current effect (in case of 0.4 mm PE)}$$

$$Lns = 0 : \text{intra-quad eddy current effect (in case of 0.5 mm PVC FP)}$$

where:

$J_0, J_1, J_2$  zero-, first-, and second-order Bessel functions

$\text{Re}[\ ]$  real part in [ ]

$$\lambda \equiv (1+j) \frac{r_i}{\delta_i}$$

$r_i$ : radius of conductor [m]

$$\delta_i = \sqrt{\frac{2}{\omega \sigma_i \mu_i}} : \text{skin depth [m]}$$

$\sigma_i$ : conductivity of copper (conductor) [mho/m]

$\mu_0$ : permeability of vacuum [H/m]

$\mu_i$ : permeability of copper (conductor) [H/m]:  $= \mu_r \mu_0$

$\mu_r$ : relative permeability of copper (conductor)

$\omega$ : angular frequency [rad/s]

$d_i$ : distance between wire (conductor) centres of a pair [m]



$$d_i = 2\sqrt{2}(r_i + CO_i): \text{ in case of 0.4 mm PE}$$

$$d_i = 2(r_i + CO_i): \text{ in case of 0.5 mm PVC FP}$$

$CO_i$ : thickness of insulator for wire (conductor) [m]

**Table F.5/G.993.1 – Coefficient values**

Item	TP (0.4 mm PE)	FP (0.5mm PVC FP)
$r_i$ [m]	$0.2 \times 10^{-3}$	$0.25 \times 10^{-3}$
$CO_i$ [m]	$0.13 \times 10^{-3}$	$0.78 \times 10^{-3}$
$C_i$ [F/m]	$50 \times 10^{-12}$	$20 \times 10^{-12}$
$C_{oa}$ [F/m]	0	$20 \times 10^{-12}$
ce	0	0.095
$\tan\delta$	$5.0 \times 10^{-4}$	$1.9 \times 10^{-1}$
ge	1.16	0.895
$\sigma_i$ [mho/m]	$5.8 \times 10^7$	$5.8 \times 10^7$
$\mu_0$ [H/m]	$4\pi \times 10^{-7}$	$4\pi \times 10^{-7}$
$\mu_r$	1	1

### F.3.1.3 Line transfer function and test loop characteristics

The line transfer function (of voltage) based on the propagation constant is given below. The transfer function below assumes no impedance mismatch and perfect terminations by characteristic impedances at both ends, and is a simplified approximation.

$$H(f) = e^{\gamma_{TP} X} e^{\gamma_{FP} Y}$$

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} : \text{ propagation constant}$$

X, Y: line distance [m]

The test loop characteristics for reference are presented in Tables F.6, F.7, and F.8 as results of calculation using the above line transfer function and coefficient values.

NOTE – The insertion loss with a source impedance of 100  $\Omega$  and a terminal impedance of 100  $\Omega$  should be calculated by using the loop ABCD parameters, and the result is loop length and composition dependent.

**Table F.6/G.993.1 – Test loop image attenuation in dB for reference**

Loop type	Loop length	Frequency [MHz]									
		$f_1$	$f_{1j}$		$f_2$		$f_3$		$f_4$		$f_5$
		0.138	0.640	2.195	3.75	4.475	5.20	6.85	8.50	10.25	12.00
TP	300 m	3.27 dB	6.13	11.8	15.7	17.3	18.7	21.8	24.6	27.4	30.0
FP	50 m	0.27 dB	0.57	1.22	1.74	1.96	2.18	2.65	3.09	3.54	3.98

**Table F.7/G.993.1 – Test loop group delay in  $\mu\text{s}$  (micro-second) for reference**

Loop type	Loop length	Frequency [MHz]									
		$f_1$	$f_{1j}$		$f_2$		$f_3$		$f_4$		$f_5$
		0.138	0.640	2.195	3.75	4.475	5.20	6.85	8.50	10.25	12.00
TP	300 m	1.73 $\mu\text{s}$	1.63	1.58	1.57	1.57	1.57	1.56	1.56	1.56	1.56
FP	50 m	.24 $\mu\text{s}$	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.22

**Table F.8/G.993.1 – Test loop characteristic impedance in  $\Omega$  (ohm) for reference**

Loop type	Frequency [MHz]									
	$f_1$	$f_{1j}$		$f_2$		$f_3$		$f_4$		$f_5$
	0.138	0.640	2.195	3.75	4.475	5.20	6.85	8.50	10.25	12.00
TP	125 $\Omega$	114	109	107	107	107	107	107	107	107
FP	191 $\Omega$	188	187	187	187	187	187	187	187	188

**F.3.2 Crosstalk disturbers****F.3.2.1 Disturber types**

Crosstalk margin measurements are performed with several types of disturbers, VDSL (ITU-T Rec. G.993.1) self, TCM-ISDN DSL (Appendix III/G.961), ADSL (Annex C/G.992.1 DBM), and PNT (ITU-T Rec. G.989.1).

Two kinds of noise models are defined as follows. Noise A and Noise  $B_j$  ( $j = 1$  to 4).

- 1) Noise A only or Noise A + each Noise  $B_j$  ( $j = 1$  or 2 or 3 or 4) shall be injected at each UI or UO port defined in Figure F.10, and the test should be performed several (3 to 4) times.
  - A combination Noise  $B_j$  and Noise  $B_k$  ( $j > k$ ) is not used for performance test. Also, simultaneous injection at both UI and UO ports is not used.
  - Noise A = -140 dBm/Hz AWGN (Additive White Gaussian Noise)
  - Noise  $B_1$  = 9 VDSL self NEXT and FEXT (see F.3.2.2 for the disturber PSD)
  - Noise  $B_2$  = 9 ADSL NEXT and FEXT (see ITU-T Rec. G.996.1 for the disturber PSD)
  - Noise  $B_3$  = 9 PNT NEXT (see F.3.2.2 and ITU-T Rec. G.989.1 for the disturber PSD)
  - Noise  $B_4$  = 9 TCM-ISDN DSL alternate NEXT and FEXT (see ITU-T Rec. G.996.1 for the disturber PSD)

NOTE 1 – PNT NEXT and FEXT appear alternately in the same frequency band, and are not cyclostationary. This annex adopts only NEXT injection for VDSL test purposes as significant crosstalk.

NOTE 2 – TCM-ISDN DSL NEXT and FEXT appear alternately in the same frequency band, and are cyclostationary. This annex adopts cyclostationary crosstalk injection of NEXT and FEXT for VDSL test purposes as defined in ITU-T Rec. G.996.1 for ADSL test purposes.

NOTE 3 – VDSL and ADSL NEXT injection is for testing input signal dynamic range of a VDSL receiver.



- 2) Only intra-quad condition is defined for Noise B.

The XT PSL (crosstalk power sum loss) values for 9 disturbers with 1% worst case are defined below. This is the reason why the PE insulated cable adopts a unit binding five quads (= ten pairs), so the maximum number of disturbers within a unit is nine.

$NPSL9$  (NEXT PSL) = 49.5 dB at  $f_{NEXT} = 160 \times 10^3$  Hz

$FPSL9$  (FEXT PSL) = 51.5 dB at  $f_{FEXT} = 160 \times 10^3$  Hz and  $d_{FEXT} = 1 \times 10^3$  m

- 3) Only the TP ( $X_1$ ) section in Figure F.10 shall be considered as crosstalk coupling path. That is the TP ( $X_2$ ) section (BT) shall not be incorporated in the simulated FEXT disturber PSD as part of FEXT coupling path. As for the FP section in Figure F.10, no crosstalk is considered since the FP is a single pair.

### F.3.2.2 Power spectral density of disturbers

The single-sided power spectral density (PSD) functions in watts/Hz for TCM-ISDN DSL and ADSL disturbers are defined in ITU-T Rec. G.996.1. Those for VDSL disturbers are shown in F.3.2.2.1 which are compliant to the PSD requirements specified in F.1. PNT PSD is defined in ITU-T Rec. G.989.1, and is reproduced in F.3.2.2.2.

#### F.3.2.2.1 VDSL disturber PSD

Two kinds of VDSL disturber PSD are defined. One is for a VDSL that enables coexistent operation with POTS on the same wire-pair by using the frequencies above 0.138 MHz ( $= f_1$ ). The other is for a VDSL that enables coexistent operation with TCM-ISDN DSL on the same wire-pair by using the frequencies above 0.64 MHz ( $= f_{1,I}$ ). Both of them are abbreviated VDSL-x, where  $x = P$  (POTS) and  $x = I$  (ISDN). The VDSL-I downstream disturber PSD is different from the VDSL-P downstream disturber PSD, so they are abbreviated VDSL-I-DS and VDSL-P-DS. Meanwhile, the upstream disturber PSD of VDSL-I are the same as that of VDSL-P, so both are abbreviated VDSL-US.

The single-sided PSD of VDSL-P and VDSL-I downstream disturbers in watts/Hz are expressed as follows. Also, the single-sided PSD of VDSL upstream disturber in watts/Hz is expressed as follows.

$$PSD_{VDSL-P-DS}(f) = 10^{\frac{KDS-P(f)}{10}-3} \text{ watts/Hz}$$

$$PSD_{VDSL-I-DS}(f) = 10^{\frac{KDS-I(f)}{10}-3} \text{ watts/Hz}$$

$$PSD_{VDSL-US}(f) = 10^{\frac{KUS-I(f)}{10}-3} \text{ watts/Hz}$$

where:

$$\begin{aligned} f_1 &= 0.138 \times 10^6 \text{ Hz} \\ f_{1,I} &= 0.64 \times 10^6 \text{ Hz} \\ f_2 &= 3.75 \times 10^6 \text{ Hz} \\ f_3 &= 5.2 \times 10^6 \text{ Hz} \\ f_4 &= 8.5 \times 10^6 \text{ Hz} \\ f_5 &= 12 \times 10^6 \text{ Hz} \\ \Delta f_T &= 0.175 \times 10^6 \text{ Hz: transition band at } f_1, f_2, f_3, f_4, \text{ and } f_5 \\ \Delta f_{TX} &= 0.018 \times 10^6 \text{ Hz: transition band at } f_1 \end{aligned}$$

KDS-P( $f$ )	-120	dBm/Hz	$0 \text{ Hz} < f < 0.12 \times 10^6 \text{ Hz}$
	$-60 + (50 / \Delta f_{TX}) \times (f - f_1)$	dBm/Hz	$f_1 - \Delta f_{TX} \leq f \leq f_1$
	-60	dBm/Hz	$f_1 < f < f_2$
	$-80 - (20 / \Delta f_T) \times (f - f_2)$	dBm/Hz	$f_2 \leq f \leq f_2 + \Delta f_T$
	-100	dBm/Hz	$f_2 + \Delta f_T < f < f_3 - \Delta f_T$
	$-80 + (20 / \Delta f_T) \times (f - f_3)$	dBm/Hz	$f_3 - \Delta f_T \leq f \leq f_3$
	-60	dBm/Hz	$f_3 < f < f_4$
	$-80 - (20 / \Delta f_T) \times (f - f_4)$	dBm/Hz	$f_4 \leq f \leq f_4 + \Delta f_T$
	-100	dBm/Hz	$f_4 + \Delta f_T < f < 30 \times 10^6 \text{ Hz}$
	-120	dBm/Hz	$30 \times 10^6 \text{ Hz} \leq f < \infty$
KDS-I( $f$ )	-120	dBm/Hz	$0 \text{ Hz} < f < 0.12 \times 10^6 \text{ Hz}$
	-110	dBm/Hz	$0.12 \times 10^6 \text{ Hz} \leq f < 0.225 \times 10^6 \text{ Hz}$
	-100	dBm/Hz	$0.225 \times 10^6 \text{ Hz} \leq f < f_{1J} - \Delta f_T$
	$-60 + (40 / \Delta f_T) \times (f - f_{1J})$	dBm/Hz	$f_{1J} - \Delta f_T \leq f \leq f_{1J}$
	-60	dBm/Hz	$f_{1J} < f < f_2$
	$-80 - (20 / \Delta f_T) \times (f - f_2)$	dBm/Hz	$f_2 \leq f \leq f_2 + \Delta f_T$
	-100	dBm/Hz	$f_2 + \Delta f_T < f < f_3 - \Delta f_T$
	$-80 + (20 / \Delta f_T) \times (f - f_3)$	dBm/Hz	$f_3 - \Delta f_T \leq f \leq f_3$
	-60	dBm/Hz	$f_3 < f < f_4$
	$-80 - (20 / \Delta f_T) \times (f - f_4)$	dBm/Hz	$f_4 \leq f \leq f_4 + \Delta f_T$
	-100	dBm/Hz	$f_4 + \Delta f_T < f < 30 \times 10^6 \text{ Hz}$
	-120	dBm/Hz	$30 \times 10^6 \text{ Hz} \leq f < \infty$
KUS( $f$ )	-120	dBm/Hz	$0 \text{ Hz} < f < 0.12 \times 10^6 \text{ Hz}$
	-110	dBm/Hz	$0.12 \times 10^6 \text{ Hz} \leq f < 0.225 \times 10^6 \text{ Hz}$
	-100	dBm/Hz	$0.225 \times 10^6 \text{ Hz} \leq f < f_2 - \Delta f_T$
	$-80 + (20 / \Delta f_T) \times (f - f_2)$	dBm/Hz	$f_2 - \Delta f_T \leq f \leq f_2$
	-60	dBm/Hz	$f_2 < f < f_3$
	$-80 - (20 / \Delta f_T) \times (f - f_3)$	dBm/Hz	$f_3 \leq f \leq f_3 + \Delta f_T$
	-100	dBm/Hz	$f_3 + \Delta f_T < f < f_4 - \Delta f_T$
	$-80 + (20 / \Delta f_T) \times (f - f_4)$	dBm/Hz	$f_4 - \Delta f_T \leq f \leq f_4$
	-60	dBm/Hz	$f_4 < f < f_5$
	$-80 - (20 / \Delta f_T) \times (f - f_5)$	dBm/Hz	$f_5 \leq f \leq f_5 + \Delta f_T$
	-100	dBm/Hz	$f_5 + \Delta f_T < f < 30 \times 10^6 \text{ Hz}$
	-120	dBm/Hz	$30 \times 10^6 \text{ Hz} \leq f < \infty$

The VDSL disturber  $\text{PSD}_{\text{VDSL-P-DS}}(f)$  and  $\text{PSD}_{\text{VDSL-US}}(f)$  in dBm/Hz are presented in Figure F.11. VDSL disturber  $\text{PSD}_{\text{VDSL-I-DS}}(f)$  and  $\text{PSD}_{\text{VDSL-US}}(f)$  in dBm/Hz are presented in Figure F.12. In Figures F.11 and F.12, a solid line shows the downstream  $\text{PSD}_{\text{VDSL-X-DS}}(f)$ , and a dotted line shows the upstream  $\text{PSD}_{\text{VDSL-US}}(f)$ .

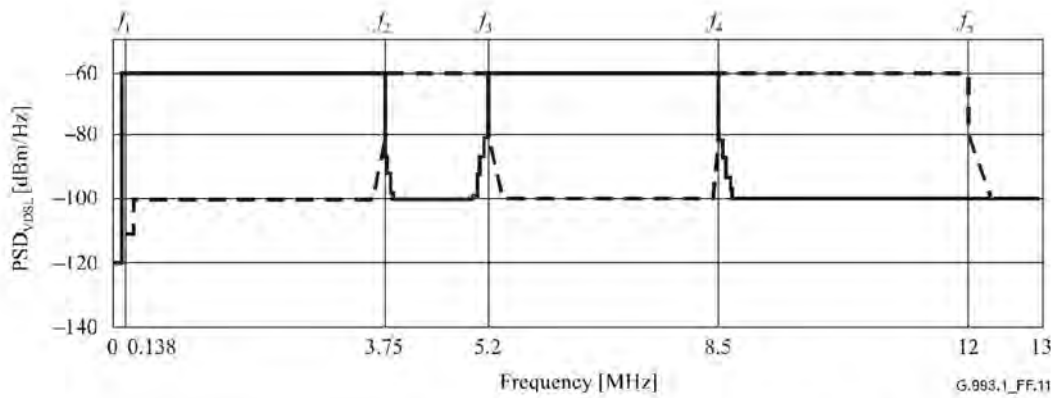


Figure F.11/G.993.1 – VDSL-P downstream and upstream disturber PSD

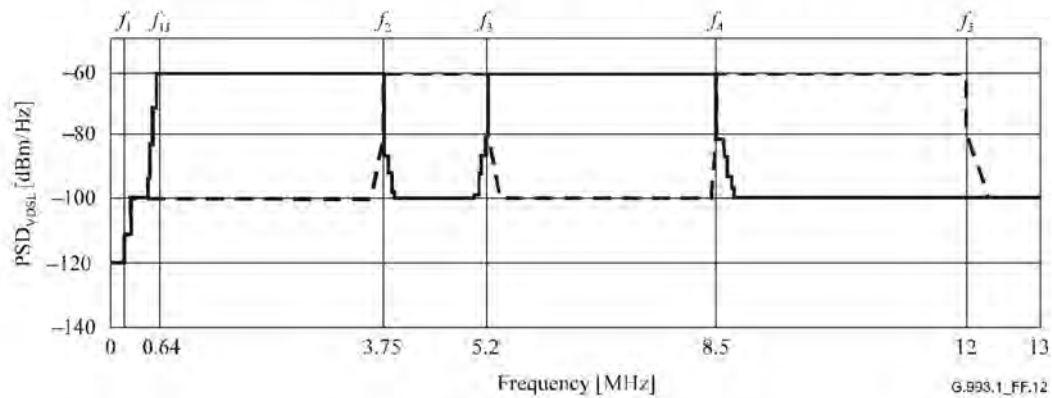


Figure F.12/G.993.1 – VDSL-I downstream and upstream disturber PSD

#### F.3.2.2.2 PNT disturber PSD

The single-sided PSD of PNT disturbers in watts/Hz, abbreviated by  $PSD_{PNT}(f)$ , is expressed as follows:

$$PSD_{PNT}(f) = 10^{\frac{KPNT(f)}{10}} \text{ watts/Hz}$$

where:

$$KPNT(f) = \begin{cases} -140 & \text{dBm/Hz} & 0.015 \times 10^6 \text{ Hz} < f \leq 1.7 \times 10^6 \text{ Hz} \\ -140 + (50.0/1.8) \times (f/10^6 - 1.7) & \text{dBm/Hz} & 1.7 \times 10^6 \text{ Hz} < f \leq 3.5 \times 10^6 \text{ Hz} \\ -90 + 17.0 \times (f/10^6 - 3.5) & \text{dBm/Hz} & 3.5 \times 10^6 \text{ Hz} < f \leq 4.0 \times 10^6 \text{ Hz} \\ -71.5 & \text{dBm/Hz} & 4.0 \times 10^6 \text{ Hz} < f < 7.0 \times 10^6 \text{ Hz} \\ -81.5 & \text{dBm/Hz} & 7.0 \times 10^6 \text{ Hz} \leq f \leq 7.3 \times 10^6 \text{ Hz} \\ -71.5 & \text{dBm/Hz} & 7.3 \times 10^6 \text{ Hz} < f < 10.0 \times 10^6 \text{ Hz} \\ -81.5 - (43.5/3.0) \times (f/10^6 - 10.0) & \text{dBm/Hz} & 10.0 \times 10^6 \text{ Hz} \leq f < 13.0 \times 10^6 \text{ Hz} \\ -125 & \text{dBm/Hz} & 13.0 \times 10^6 \text{ Hz} \leq f < 25.0 \times 10^6 \text{ Hz} \\ -140 & \text{dBm/Hz} & 25.0 \times 10^6 \text{ Hz} \leq f < 30.0 \times 10^6 \text{ Hz} \end{cases}$$

The PNT disturber  $PSD_{PNT}(f)$  in dBm/Hz is presented in Figure F.13.



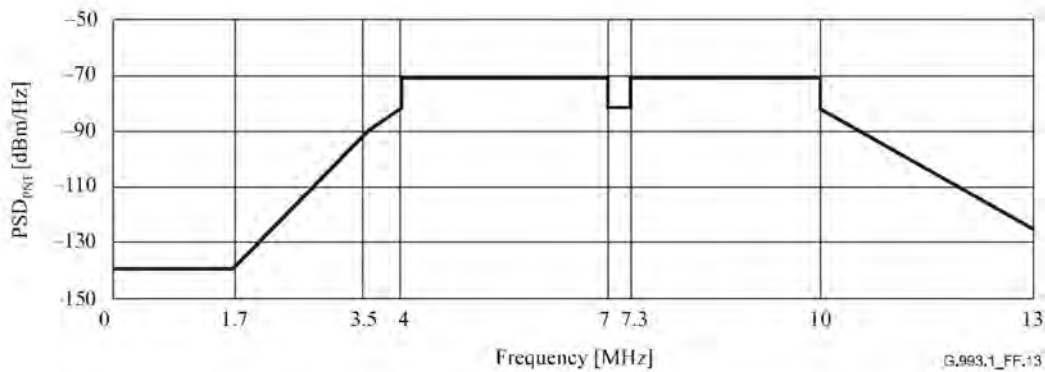


Figure F.13/G.993.1 – PNT (Phoneline Networking Transceiver) disturber PSD

### F.3.2.3 Power spectral density of crosstalk

XT (crosstalk) PSD for each xDSL disturber is given by multiplying the xDSL disturber PSD and the XT power coupling function. The XT power coupling functions  $XT(f)$  are given below for cases of NEXT and FEXT.

$$XT_{NEXT}(f) = \left( \frac{Z_{disturbed}}{Z_{disturber}} \right) 10^{-\frac{NPSL9}{10}} \left( \frac{f}{f_{NEXT}} \right)^{\frac{3}{2}}$$

$$XT_{FEXT}(f) = \left( \frac{Z_{disturbed}}{Z_{disturber}} \right) \left| e^{-2\gamma_{TP}X_1} \right| 10^{-\frac{FPSL9}{10}} \left( \frac{f}{f_{FEXT}} \right)^2 \left( \frac{X_1}{d_{FEXT}} \right)$$

where:

$f$ : frequency in Hz

$NPSL9$  = 49.5 dB at  $f_{NEXT} = 160 \times 10^3$  Hz

$FPSL9$  = 51.5 dB at  $f_{FEXT} = 160 \times 10^3$  Hz

$X_1$ : crosstalk coupling path length in m

$d_{FEXT} = 1 \times 10^3$  m

$\exp(\gamma_{TP}X_1)$ : line transfer function of TP with the length of  $X_1$  m

$Z_{disturbed}$ : termination impedance of disturbed VDSL (= 100  $\Omega$ )

$Z_{disturber}$ : termination impedance of disturbing xDSL

100  $\Omega$ : for VDSL, ADSL, and PNT

110  $\Omega$ : for TCM-ISDN

NOTE 1 – The NEXT power coupling function of  $XT_{NEXT}(f)$  is a function of a coupling path length, to be exact, as expressed below. However, this annex does not adopt the equation so as to reduce test parameters.

$$XT_{NEXT}(f) = \left( \frac{Z_{disturbed}}{Z_{disturber}} \right) 10^{-\frac{NPSL9}{10}} \left( \frac{f}{f_{NEXT}} \right)^{\frac{3}{2}} \left( 1 - \left| e^{-4\gamma_{TP}X_1} \right| \right)$$

NOTE 2 – This annex assumes FEXT coupling to be equal level coupling, i.e., a line length of a disturbed xDSL is the same as that of a disturbing xDSL, so as to reduce test parameters.

**F.3.2.3.1 VDSL XTPSD**

The single-sided XTPSD of VDSL downstream NEXT and FEXT are given below.

$$\text{XTPSD}_{\text{VDSL-}x\text{-DS-NEXT}}(f) = \text{PSD}_{\text{VDSL-}x\text{-DS}}(f) \text{XT}_{\text{NEXT}}(f) \text{ watts/Hz}$$

$$\text{XTPSD}_{\text{VDSL-}x\text{-DS-FEXT}}(f) = \text{PSD}_{\text{VDSL-}x\text{-DS}}(f) \text{XT}_{\text{FEXT}}(f) \text{ watts/Hz}$$

where  $x = \text{P or I}$ .

The single-sided XTPSD of VDSL upstream NEXT and FEXT are given below.

$$\text{XTPSD}_{\text{VDSL-US-NEXT}}(f) = \text{PSD}_{\text{VDSL-US}}(f) \text{XT}_{\text{NEXT}}(f) \text{ watts/Hz}$$

$$\text{XTPSD}_{\text{VDSL-US-FEXT}}(f) = \text{PSD}_{\text{VDSL-US}}(f) \text{XT}_{\text{FEXT}}(f) \text{ watts/Hz}$$

NOTE – The VDSL upstream disturber signal PSD ( $\text{PSD}_{\text{VDSL-US}}(f)$ ) transmitted at UR port to the line attenuates at UI port as passing through the FP section with the length of  $Y_1$  m. Thus, XTPSD is expressed as follows, to be exact. However, this annex does not adopt the equations below so as to reduce test parameters, since the simulated XTPSDs for injection at UI and UO ports become dependent on the length of  $Y_1$  if below are adopted.

$$\text{XTPSD}_{\text{VDSL-US-NEXT}}(f) = \text{PSD}_{\text{VDSL-US}}(f) |\exp(-4\gamma_{\text{FP}} Y_1)| \text{XT}_{\text{NEXT}}(f) \text{ watts/Hz}$$

$$\text{XTPSD}_{\text{VDSL-US-FEXT}}(f) = \text{PSD}_{\text{VDSL-US}}(f) |\exp(-2\gamma_{\text{FP}} Y_1)| \text{XT}_{\text{FEXT}}(f) \text{ watts/Hz}$$

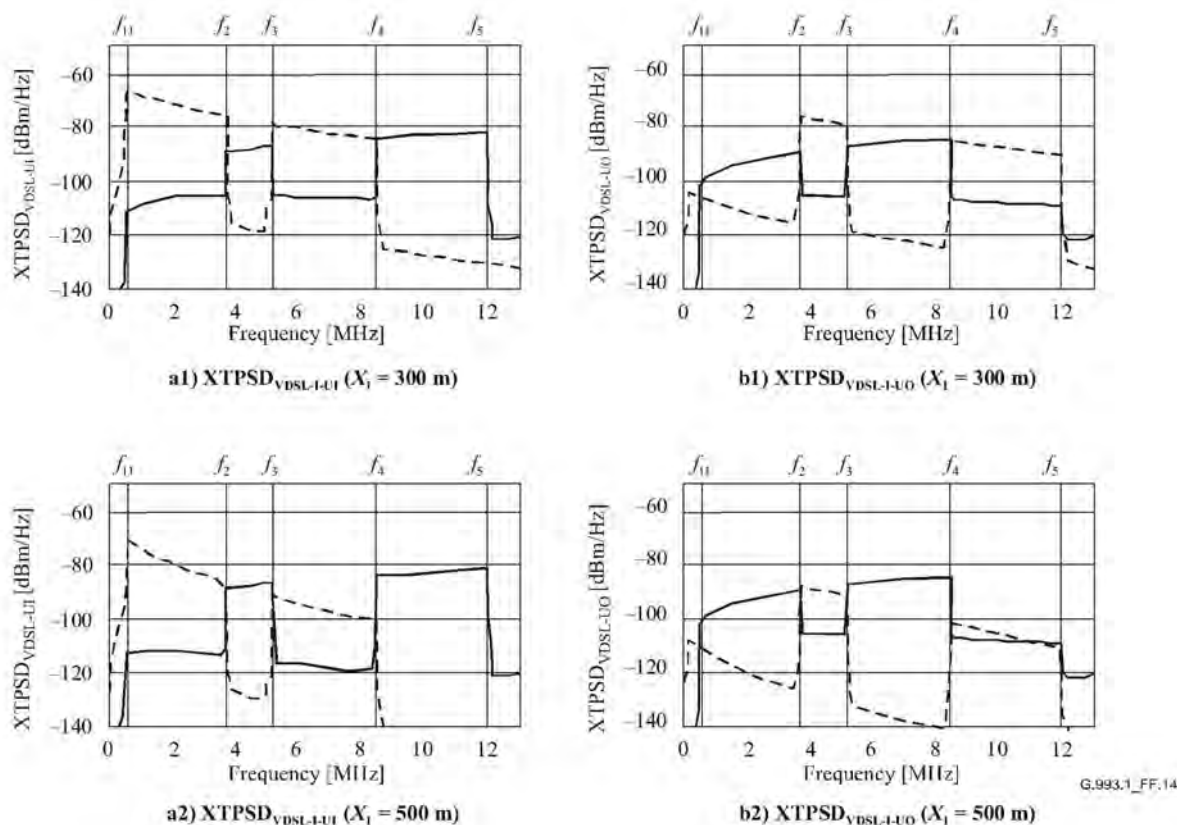
The single-sided XTPSD of VDSL self for injection at each UI or UO port is given below, where UI port is the VTU-R side and UO port is the VTU-O side as defined in Figure F.10.

$$\text{XTPSD}_{\text{VDSL-}x\text{-UI}}(f) = \text{XTPSD}_{\text{VDSL-US-NEXT}}(f) + \text{XTPSD}_{\text{VDSL-}x\text{-DS-FEXT}}(f) \text{ watts/Hz}$$

$$\text{XTPSD}_{\text{VDSL-}x\text{-UO}}(f) = \text{XTPSD}_{\text{VDSL-}x\text{-DS-NEXT}}(f) + \text{XTPSD}_{\text{VDSL-US-FEXT}}(f) \text{ watts/Hz}$$

The calculation results of VDSL-I XTPSD are shown in Figure F.14 for the cases of the TP lengths ( $X_1$ ) of 300 m and 500 m with the FP length of 0 m, where a solid line shows  $\text{XTPSD}_{\text{VDSL-I-UI}}(f)$  and  $\text{XTPSD}_{\text{VDSL-I-UO}}(f)$  in dBm/Hz, and a dotted line shows received signal PSD at UR (= UI in this case) and UO ports,  $\text{PSD}_{\text{VDSL-I-DS}}(f) \times |\exp(-2\gamma_{\text{TP}} X_1)|$  and  $\text{PSD}_{\text{VDSL-US}}(f) \times |\exp(-2\gamma_{\text{TP}} X_1)|$  in dBm/Hz, for reference.





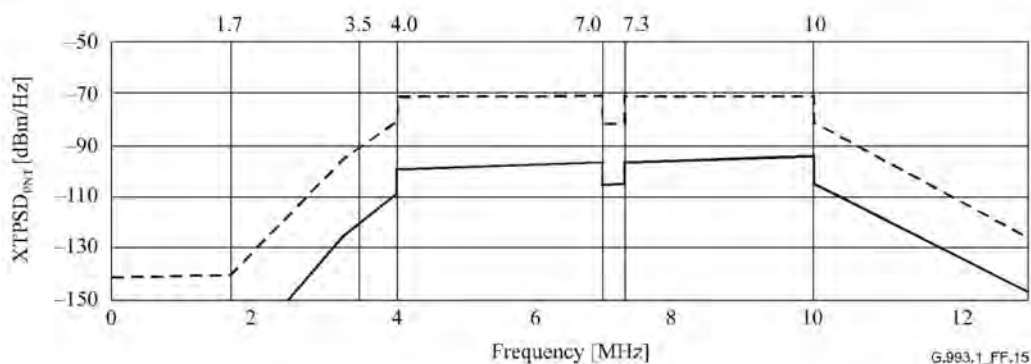
**Figure F.14/G.993.1 – 9-disturber VDSL-I NEXT and FEXT PSD for injection at UI and UO ports**

### F.3.2.3.2 PNT XTPSD

The single-sided XTPSD of PNT for injection at each UI or UO port is given below, where the upstream disturber signal attenuation through the FP section is ignored as mentioned above.

$$XTPSD_{PNT}(f) = PSD_{PNT}(f) X_{T_{NEXT}}(f) \text{ watts/Hz}$$

The calculation result of PNT XTPSD is shown in Figure F.15, where a solid line shows  $XTPSD_{PNT}(f)$  in dBm/Hz and a dotted line shows transmit signal PSD,  $PSD_{PNT}(f)$ , in dBm/Hz for reference.



**Figure F.15/G.993.1 – 9-disturber PNT NEXT PSD for injection at UI and UO ports**

### F.3.2.4 Power of crosstalk

A disturber crosstalk power in watts to be injected into a disturbed xDSL receiver is calculated by integration of power spectral density of crosstalk,  $XTPSD(f)$ , over frequencies. The numerical integration results in dBm over the frequency range from 0 Hz to 30 MHz are presented in Table F.9 for reference.

NOTE 1 – ADSL disturber crosstalk power for non-overlapped spectrum defined in Annex A/G.992.1 is given in Table F.9.

NOTE 2 – NEXT and FEXT power of TCM-ISDN DSL disturber in Table F.9 is given by assuming the transmit signal of TCM-ISDN DSL to be continuous. Cyclostationary NEXT and FEXT injection timing is shown in Figure F.16, which is reproduced from ITU-T Rec. G.996.1.

**Table F.9/G.993.1 – Crosstalk power in dBm to be injected into disturbed xDSL receiver**

Disturber	Injection port	Crosstalk power [dBm]							
		Abbreviation	Item	$X_i$ (TP length) with $Y_0 = 0$ m (FP length)					
				100 m	200 m	300 m	500 m	1000 m	1500 m
VDSL-P	UI	$XTPSD_{VDSL-P,UI}$	$XTPSD_{VDSL-P,US-NEXT}$	-16.4	←	←	←	←	←
			$XTPSD_{VDSL-P,DS-FEXT}$	-30.1	-33.7	-37.9	-45.6	-58.7	-67.7
			(power sum)	-16.3	-16.4	-16.4	-16.4	-16.4	-16.4
	UO	$XTPSD_{VDSL-P,UO}$	$XTPSD_{VDSL-P,DS-NEXT}$	-19.1	←	←	←	←	←
			$XTPSD_{VDSL-P,US-FEXT}$	-28.4	-33.8	-40.0	-51.6	-77.9	-102.6
			(power sum)	-18.6	-18.9	-19.0	-19.1	-19.1	-19.1
VDSL-I	UI	$XTPSD_{VDSL-I,UI}$	$XTPSD_{VDSL-I,US-NEXT}$	-16.4	←	←	←	←	←
			$XTPSD_{VDSL-I,DS-FEXT}$	-30.1	-33.7	-38.0	-45.8	-60.5	-72.4
			(power sum)	-16.3	-16.4	-16.4	-16.4	-16.4	-16.4
	UO	$XTPSD_{VDSL-I,UO}$	$XTPSD_{VDSL-I,DS-NEXT}$	-19.1	←	←	←	←	←
			$XTPSD_{VDSL-I,US-FEXT}$	-28.4	-33.8	-40.0	-51.6	-77.9	-102.6
			(power sum)	-18.6	-18.9	-19.0	-19.1	-19.1	-19.1
ADSL	UI	$XTPSD_{ADSL,UI}$	$XTPSD_{ADSL,US-NEXT}$	-43.1	←	←	←	←	←
			$XTPSD_{ADSL,DS-FEXT}$	-33.4	-32.6	-33.1	-35.1	-41.9	-48.9
			(power sum)	-33.0	-32.3	-32.6	-34.4	-39.5	-42.1
	UO	$XTPSD_{ADSL,UO}$	$XTPSD_{ADSL,DS-NEXT}$	-24.5	←	←	←	←	←
			$XTPSD_{ADSL,US-FEXT}$	-57.3	-55.3	-54.6	-54.4	-56.4	-59.6
			(power sum)	-22.5	-22.5	-22.5	-22.5	-22.5	-22.5
PNT	UI and UO	$XTPSD_{PNT}$	$XTPSD_{PNT-NEXT}$	-28.7	←	←	←	←	←
TCM-ISDN DSL	UI and UO	$XTPSD_{TCM-ISDN}$	$XTPSD_{TCM-ISDN-NEXT}$	-29.6	←	←	←	←	←
			$XTPSD_{TCM-ISDN-FEXT}$	-41.8	-40.4	-40.1	-40.8	-44.5	-49.0

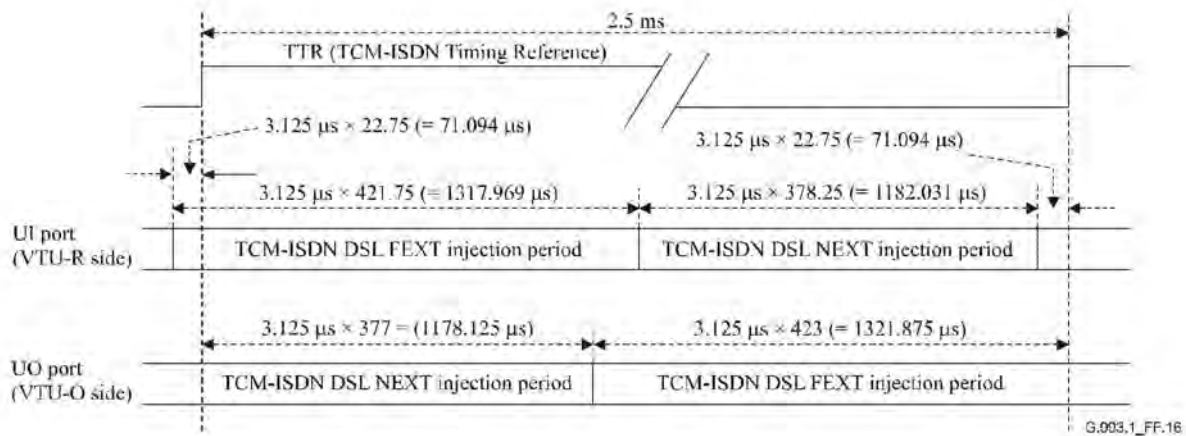


Figure F.16/G.993.1 – TCM-ISDN DSL alternate NEXT and FEXT injection timing

## Annex G

### ATM-TC

#### G.1 Scope

This annex specifies a VDSL ATM Transport Protocol Specific Transmission Convergence sublayer (ATM-TC), which describes the ATM-based service transmission over a VDSL link. This annex defines a minimum set of requirements to deliver an ATM service from the ONU to the remote customer premises. It is based on ITU-T Rec. I.432.1. The ATM-TC specification is applicable at both the VTU-O and the VTU-R sides.

#### G.2 Reference model for ATM transport

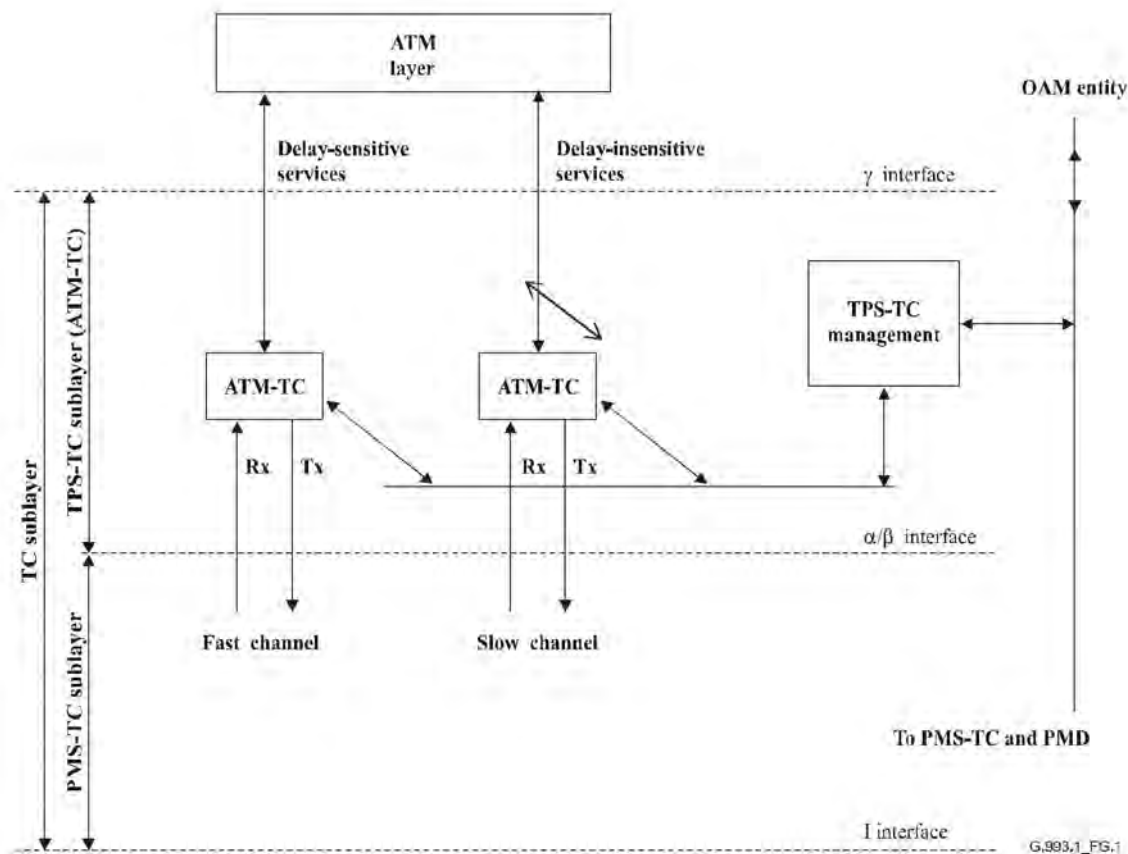
The TPS-TC sublayer for the ATM transport reference model is presented in Figure G.1. The model defines the TPS-TC sublayer located between the  $\alpha/\beta$  and  $\gamma_O/\gamma_R$  reference points.

The TPS-TC sublayer for ATM transport consists of two identical ATM TPS-TC blocks, intended to support ATM transmission over the Fast (*Delay-sensitive* applications) and the Slow (*Delay-insensitive* applications) channels. Among the two ATM channels (Fast, Slow) only the Slow channel is mandatory. The system provides Dual latency if both the Fast and the Slow channels are implemented; the system provides Single latency if only the Slow channel is implemented.

The TPS-TC OAM block provides all necessary OAM functions to support both ATM TPS-TC blocks.

The interface of both ATM TPS-TC at the  $\gamma$  reference point meets the requirements for ATM Layer interfacing (see G.4.1). Both the Fast and the Slow ATM TPS-TC have an application-independent format at the  $\alpha/\beta$  interface (see G.4.4).





NOTE – At VTU-O: Tx = Downstream, Rx = Upstream. At VTU-R: Tx = Upstream, Rx = Downstream

**Figure G.1/G.993.1 – ATM-TC reference model**

Network Timing Reference (NTR) is an 8-kHz network timing marker, which should be transported to the customer unit via the access network for some specific services. NTR is sent to the VTU-O TC across the  $\gamma_O$  interface and then transported to VTU-R. NTR is recovered in the PMS\_TC of the VTU-R and delivered to the customer unit across the  $\gamma_R$  interface. The method of transporting the NTR has not yet been determined.

### G.3 Transport of ATM data

To transport the ATM data both the upstream and the downstream channels shall be set independently from each other to any of the eligible bit rates up to the maximum aggregate channel capacity, determined by the physical net data rate (PMS-TC sublayer). The last is set during the system configuration.

The channelization of different user payloads into either the Fast or the Slow channel is embedded within the ATM data stream by using different Virtual Paths and/or Virtual Channels. To meet the basic requirements for ATM data transport, a G.993.1 system shall support ATM data transport at least in a single latency mode (one downstream channel and one upstream channel).

The need for a single or a dual latency channel for ATM transport depends on the type of service (application). One of the three possible "latency classes" may be used:

- Latency Class 1: single latency both upstream and downstream (not necessarily the same for each direction of transmission) – *mandatory*.
- Latency Class 2: dual latency downstream, single latency upstream – *optional*.

- Latency Class 3: dual latency both upstream and downstream – *optional*.

NOTE – For single latency applications, the Slow channel may be used to implement the Fast channel as well by changing its interleaving depth. Particularly, the interleaver may be disabled in the Slow channel by setting the interleaver depth to 0.

#### **G.4 ATM Transport Protocol Specific TC (ATM\_TC)**

##### **G.4.1 Application interface description ( $\gamma$ reference point)**

The  $\gamma$  reference point defines both the  $\gamma_O$  and  $\gamma_R$  interfaces at the VTU-O and VTU-R sites respectively, as shown in Figure G.1. Both  $\gamma$  interfaces are hypothetical and identical. The interfaces are defined by the following flows of signals between the ATM layer and the ATM-TC sublayer:

- data flow;
- synchronization flow;
- control flow;
- OAM flow.

NOTE 1 – If the dual latency is applied, the  $\gamma$  interface comprises two identical Data flows, Synchronization flows and Control flows – each between the corresponding ATM TPS-TC and ATM layer.

NOTE 2 – For a dual latency implementation ATM cell de-multiplexing to (multiplexing from) the appropriate ATM-TPS TC (i.e., Fast and Slow channel) could be performed at the ATM layer based on the Virtual Path Identifier (VPI) and Virtual Connection Identifier (VCI), both contained in the ATM cell header.

##### **G.4.1.1 Data flow**

The Data flow consists of two streams of 53 octet ATM cells each (Tx\_ATM, Rx\_ATM) with independent rates flowing in opposite directions. Rate values are arbitrary under a predefined upper limit of aggregate channel capacity determined by the data rate at the corresponding  $\alpha$  (or  $\beta$ ) interface. The Data flow signal description is presented in Table G.1.

**Table G.1/G.993.1 – ATM-TC:  $\gamma$  interface data, synchronization and control flows signal summary**

Flow	Signal	Description	Direction	Notes
<i>Transmit signals</i>				
Data	<i>Tx_ATM</i>	Transmit cell	ATM → ATM-TC	
Sync	<i>Tx_Clk</i>	Transmit timing	ATM → ATM-TC	
Sync	<i>TxSOC</i>	Start of the transmit cell	ATM → ATM-TC	
Sync	<i>TxClAv</i>	TPS-TC is ready to get a cell	ATM ← ATM-TC	
Control	<i>Enbl_Tx</i>	TPS-TC polling for an incoming cell	ATM → ATM-TC	
NTR	<i>TxRef</i>	8-kHz NTR	VTU-O → ATM-TC	VI_O only
<i>Receive signals</i>				
Data	<i>Rx_ATM</i>	Receive cell	ATM ← ATM-TC	
Sync	<i>Rx_Clk</i>	Receive timing	ATM → ATM-TC	
Sync	<i>RxSOC</i>	Start of the receive cell	ATM ← ATM-TC	
Sync	<i>RxClAv</i>	TPS-TC is ready to transmit a cell	ATM ← ATM-TC	
Control	<i>Enb_Rx</i>	TPS-TC polling for the outgoing cell	ATM → ATM-TC	
NTR	<i>RxRef</i>	8-kHz NTR	VTU-R ← ATM-TC	VI-R only



The ATM cell format is identical in both transmit and receive directions: 52 out of the 53 octets carry ATM layer data (user data). Octet number 5 is undefined (intended for HEC insertion in the TC sublayer).

NOTE 1 – If data streams are *serial* by implementation, the MSB of each octet is sent first.

NOTE 2 – The Data flow signals are amenable to UTOPIA interface implementation [ATMF].

#### **G.4.1.2 Synchronization flow**

This flow provides synchronization between the ATM layer and the ATM-TC sublayer and includes both ATM data synchronization signals and the Network Timing reference signal.

The Synchronization flow comprises the following signals, presented in Table G.1:

- Transmit and receive timing signals (Tx\_Clk, Rx\_Clk); both asserted by ATM layer;
- Start-of-Cell marker (TxSOC, RxSOC): bidirectional signal, intended to identify the beginning of the transported cell in the corresponding direction;
- Transmit Cell Available flag (TxClAv), asserted by ATM TPS-TC: indicates that ATM TPS-TC is ready to get a transmitted cell from the ATM layer;
- Receive Cell Available flag (RxClAv), asserted by ATM TPS-TC: indicates that TPS-TC contains a valid cell and is ready to transmit it towards ATM layer;
- Transmit Timing Reference (TxRef), applied at the VTU-O only: an 8-kHz NTR signal incoming from the network;
- Receive Timing Reference (RxRef): an 8-kHz NTR signal, recovered from the received VDSL signal at the VTU-R.

NOTE 1 – The Tx\_Clk and the Rx\_Clk rates are matched with the Tx\_ATM and the Rx\_ATM data rates respectively.

NOTE 2 – Network Timing Reference signals have opposite directions at the VTU-O and the VTU-R.

NOTE 3 – The Synchronization flow signals are amenable to UTOPIA interface implementation [Appendix I].

#### **G.4.1.3 Control flow**

Two control signals are used to provide multiple ATM TPS-TC connection. Both are asserted by the ATM layer:

- Transmit Enable signal (Enbl\_Tx): indicates to the ATM TPS-TC that the next transmitted Tx\_ATM cell is valid;
- Receive Enable signal (Enbl\_Rx): allows the ATM TPS-TC to transmit a Rx\_ATM cell towards the ATM layer.

NOTE – The Control flow signals are amenable to UTOPIA interface implementation [Appendix I].

#### **G.4.1.4 OAM flow**

The OAM flow across the  $\gamma$  interface exchanges OAM information between the OAM entity and its ATM related TPS-TC management functions. OAM flow is bidirectional.

### **G.4.2 ATM TPS-TC functionality**

The following ATM TPS-TC functionality should be applied both to the downstream and upstream transmission directions.

#### **G.4.3 Cell rate decoupling**

Cell rate decoupling should be implemented by Idle cells insertion in the transmit direction and Idle cells deletion in the receive direction (at the remote ATM TPS-TC), as specified in ITU-T Rec. I.432.1. A standard cell header, also specified in ITU-T Rec. I.432.1, identifies idle cells.

#### G.4.3.1 HEC generation/verification

The HEC byte shall be generated as described in ITU-T Rec. I.432.1, including the recommended modulo-2 addition (XOR) of the pattern  $01010101_2$  to the HEC bits. The generator polynomial coefficient set used and the HEC sequence generation procedure shall be in accordance with ITU-T Rec. I.432.1.

The HEC sequence shall be capable of multiple-bit error detection, as defined in ITU-T Rec. I.432.1. The single bit error correction of the cell header shall not be performed.

#### G.4.3.2 Cell payload randomization and de-randomization

Randomization of the transmit ATM cell payload avoids continuous non-variable bit patterns in the ATM cell stream and so improves the efficiency of the cell delineation algorithm.

The ATM cell randomizer uses a self-synchronizing scrambler polynomial  $x^{43} + 1$  and randomization procedures as defined in ITU-T Rec. I.432.1 for STM-based transmission shall be implemented. The corresponding de-randomization process should be implemented at the remote ATM TPS-TC.

#### G.4.3.3 Cell delineation

The cell delineation function permits the identification of the cell boundaries in the payload. It is based on a coding law using the Header Error Control (HEC) field in the cell header.

The cell delineation algorithm should be as described in ITU-T Rec. I.432.1. It includes the following states and state transitions, presented in Figure G.2:

- "Sync" to "Hunt" state transition when HEC coding law is violated  $\alpha = 5$  times consecutively.
- "Presync" to "Sync" state transition when HEC coding law is confirmed  $\delta = 7$  times consecutively.

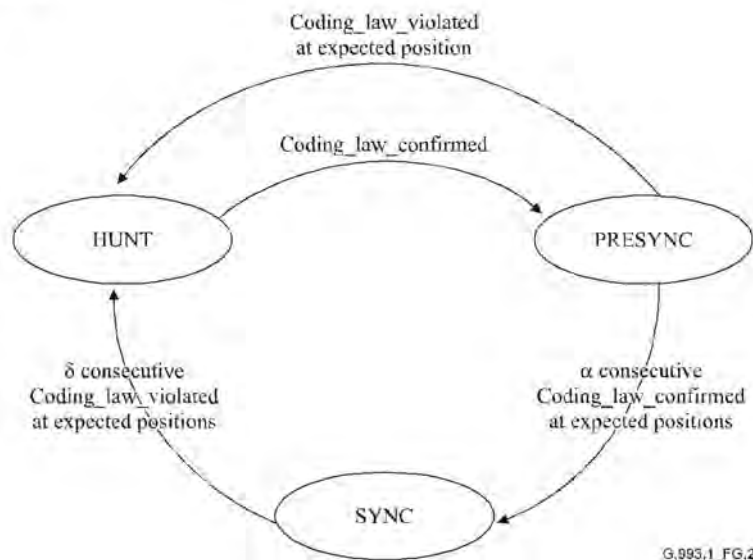


Figure G.2/G.993.1 – ATM cell delineation state machine

#### G.4.4 $\alpha(\beta)$ interface

The  $\alpha$  and  $\beta$  reference points define interfaces between the ATM-TC and PMS-TC at the VTU-O and VTU-R respectively. Both interfaces are functional, application independent, and should comply with the generic definition for all TPS-TC as specified in clause 7.



## Annex H

### PTM-TC

#### H.1 Packetized data transport

##### H.1.1 Functional model

The functional model of packetized data transport is presented in Figure H.1. In the transmit direction, the *PTM entity* obtains data packets to be transported over VDSL from the application interface. The PTM entity processes each packet and applies it (depending on the latency requirements) to the  $\gamma$  interface of the either Fast or Slow VDSL path intended for packetized data transport. The corresponding TPS-TC (PTM-TC) receives the packet from the  $\gamma$  interface, encapsulates it into a special frame (PTM-TC frame) and maps into the PMS-TC frame (transmission frame) for transmission over the VDSL link.

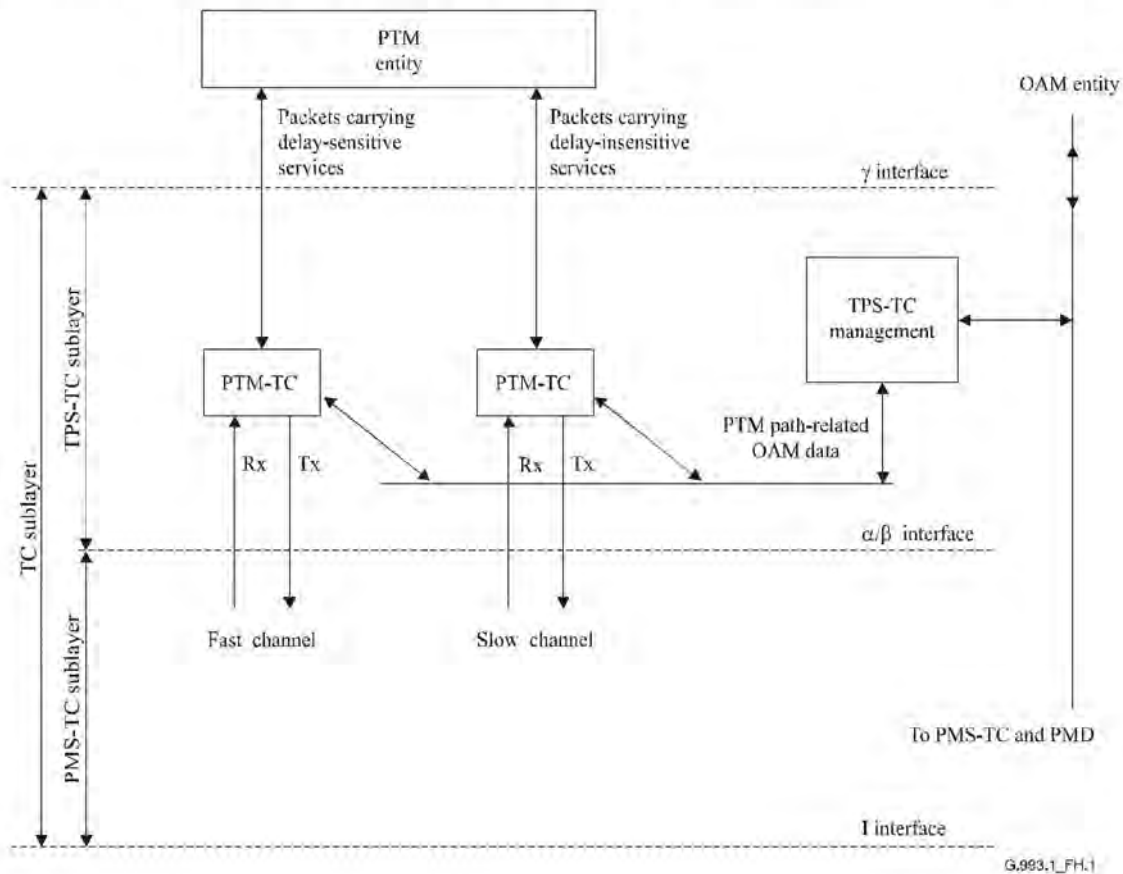


Figure H.1/G.993.1 – Functional model of PTM transport

In the receive direction, the PTM-TC frame extracted from the received PMS-TC frame is directed into the PTM-TC. The PTM-TC recovers the transported packet and delivers it to the PTM entity via the  $\gamma$  interface.

The PTM path-related OAM data, including information on errored packets, shall be presented to the TPS-TC management entity providing all necessary OAM functions to support both PTM-TC.

The  $\gamma$  interfaces of both PTM-TC are identical and described in H.3.1. The  $\alpha/\beta$  interfaces are application independent and thus has the same format as for other TPS-TC (see H.3.1.5).

## H.2 Transport of PTM data

The bit rate of PTM data transport in the upstream and downstream directions may be set independently of each other to any eligible value which is less than the assigned maximum bit rate in the corresponding direction. Both the upstream and downstream maximum bit rates for PTM transport are set during the system configuration.

The PTM transport could be arranged using either Slow channel or Fast channel or both. The PTM-TC supporting either channel has the same characteristics. The mandatory configuration for packet transport shall include one PTM-TC (either Fast or Slow). The second PTM-TC is optional.

If PTM is the only transport established over the VDSL link, usage of Slow channel is the mandatory configuration for single latency in accordance with the generic TPS-TC sublayer architecture. The required latency should be obtained by adjustment of the interleaving depth.

The PTM-TC shall provide full transparent data transfer between  $\gamma_O$  and  $\gamma_R$  interfaces (except non-correctable errors in the PMD sublayer due to the noise in the loop). The PTM-TC shall provide packet integrity over either Fast or Slow channel.

## H.3 Interface description

### H.3.1 $\gamma$ interface

The  $\gamma_O$  and  $\gamma_R$  reference points define interfaces between the PTM entity and PTM-TC at the VTU-O and VTU-R respectively as shown in Figure H.1. Both interfaces are identical, functional, and independent of the contents of the transported packets. The interfaces are defined by the following flows of signals between the PTM entity and the PTM-TC sublayer:

- data flow;
- synchronization flow;
- control flow;
- OAM flow.

#### H.3.1.1 Data flow

The data flow shall consist of two contra-directional octet-based streams of packets: transmit packets (*Tx\_PT*M) and receive packets (*Rx\_PT*M). The packet transported in either direction over the  $\gamma$  interface may be of variable length. Bits within an octet are labeled  $a_1$  through  $a_8$ , with  $a_1$  being the LSB and  $a_8$  being the MSB. If either of data streams is transmitted serially, the first octet of the packet shall be transmitted first and bit  $a_1$  of each octet shall be transmitted first as shown in Figure H.3. The Data Flow signal description is presented in Table H.1.

**Table H.1/G.993.1 – PTM-TC:  $\gamma$  interface data, synchronization and control flows signal summary**

Flow	Signal	Description	Direction
<i>Transmit signals</i>			
Data	<i>Tx_PT</i> M	Transmit data	PTM → PTM-TC
Control	<i>Tx_Enbl</i>	Asserted by the PTM-TC; indicates PTM may push data to the PTM-TC	PTM ← PTM-TC
Control	<i>TX_Err</i>	Errored transmit packet (request to abort)	PTM → PTM-TC



**Table H.1/G.993.1 – PTM-TC:  $\gamma$  interface data, synchronization and control flows signal summary**

Flow	Signal	Description	Direction
Sync	<i>Tx_Avbl</i>	Asserted by the PTM entity if data is available for transmission	PTM → PTM-TC
Sync	<i>Tx_Clk</i>	Clock signal asserted by the PTM entity	PTM → PTM-TC
Sync	<i>Tx_SoP</i>	Start of the transmit Packet	PTM → PTM-TC
Sync	<i>Tx_EoP</i>	End of the transmit Packet	PTM → PTM-TC
<i>Receive signals</i>			
Data	<i>Rx_PTM</i>	Receive data	PTM ← PTM-TC
Control	<i>Rx_Enbl</i>	Asserted by the PTM-TC; indicates PTM may pull data from the PTM-TC	PTM ← PTM-TC
Control	<i>RX_Err</i>	Received error signals including FCS error, Invalid Frame, and OK	PTM ← PTM-TC
Sync	<i>Rx_Clk</i>	Clock signal asserted by the PTM entity	PTM → PTM-TC
Sync	<i>Rx_SoP</i>	Start of the receive Packet	PTM ← PTM-TC
Sync	<i>Rx_EoP</i>	End of the receive Packet	PTM ← PTM-TC

**H.3.1.2 Synchronization flow**

This flow provides synchronization between the PTM entity and the PTM-TC sublayer and contains the necessary timing to provide packet integrity during the transport. The synchronization flow shall consist of the following signals presented in Table H.1:

- Transmit and receive timing signals (*Tx\_Clk*, *Rx\_Clk*): both asserted by PTM entity.
- Start of Packet signals (*Tx\_SoP*, *Rx\_SoP*): asserted by PTM entity and by PTM-TC respectively and intended to identify the beginning of the transported packet in the corresponding direction of transmission.
- End of Packet signals (*Tx\_EoP*, *Rx\_EoP*): asserted by PTM entity and by PTM-TC respectively and intended to identify the end of the transported packet in the corresponding direction of transmission.
- Transmit Packet Available signals (*Tx\_Avbl*): asserted by PTM entity to indicate that data for transmission in the corresponding direction is ready.

**H.3.1.3 Control flow**

Control signals are used to improve robustness of data transport between the PTM-entity and PTM-TC and are presented in Table H.1.

- Enable signals (*Tx\_Enbl*, *Rx\_Enbl*): asserted by PTM-TC and indicates that data may be respectively sent from PTM entity to PTM-TC or pulled from PTM-TC to PTM entity.
- Transmit error message (*Tx\_Err*): asserted by the PTM entity and indicates that the packet or a part of the packet already transported from PTM entity to PTM-TC is errored or undesirable for transmission (abort of transmitted packet).
- Receive error message (*Rx\_Err*): shall be asserted by the PTM-TC to indicate that an errored packet is transported from PTM-TC to PTM entity.

Handling of packet errors is described in H.4.2.



### H.3.1.4 OAM flow

The OAM Flow across the  $\gamma$  interface exchanges OAM information between the OAM entity and its PTM related TPS-TC management functions. OAM flow is bidirectional.

### H.3.1.5 $\alpha(\beta)$ interface

The  $\alpha$  and  $\beta$  reference points define interfaces between the PTM-TC and PMS-TC at the VTU-O and VTU-R respectively. Both interfaces are functional, application independent, and should comply with the generic definition for all TPS-TC as specified in clause 7.

## H.4 PTM TPS-TC functionality

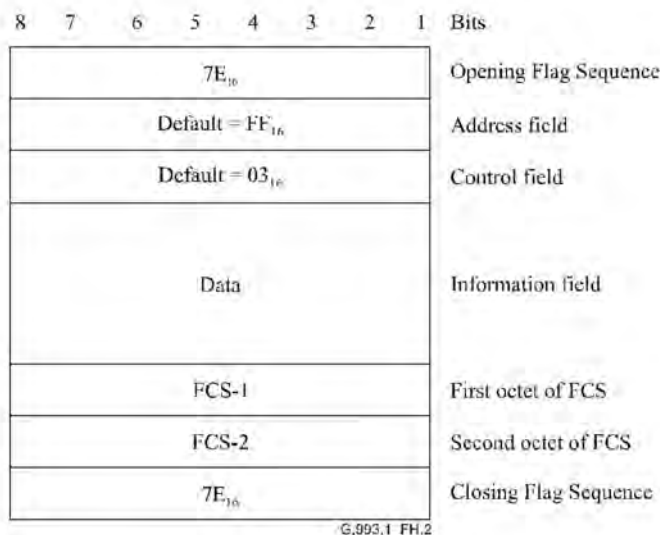
The following PTM TPS-TC functionality should be applied both to the downstream and upstream transmission directions.

### H.4.1 Packet encapsulation

For packet encapsulation, an HDLC-type mechanism shall be used with detailed characteristics as specified in the following subclauses.

#### H.4.1.1 Frame structure

The PTM-TC frame format shall be as shown in Figure H.2. The opening and closing Flag Sequences shall be set to  $7E_{16}$ . They identify the start and the end of the frame. Only one Flag Sequence is required between two consecutive frames.



**Figure H.2/G.993.1 – PTM-TC frame format**

The Address and Control octets are intended for auxiliary information. They shall be set to their default values of hexadecimal  $FF_{16}$  and  $03_{16}$  respectively if not used.

NOTE 1 – The address and Control fields may be used for different auxiliary OAM functions.

The Information field shall be filled with the transported data packet. Prior to encapsulation the octets of the data packet shall be numbered sequentially. Octets shall be transmitted in ascending numerical order.

The Frame Check Sequence (FCS) octets are used for packet level error monitoring, and shall be set as described in H.4.3.

After encapsulation, bits within an octet are labeled  $b_1$  through  $b_8$ , as defined in Figure H.3. If the  $\alpha(\beta)$  interface is serial by implementation, bit  $b_8$  of each octet shall be transmitted first.

NOTE 2 – In keeping with existing labelling convention for the  $\alpha/\beta$  interface, bit  $b_8$  (MSB) is transmitted first. The PTM-TC functionality defines a correspondence between  $a_1$  and  $b_8$ ,  $a_2$  and  $b_7$ , etc., in order to conform to the HDLC convention of transmitting bit  $a_1$  first.

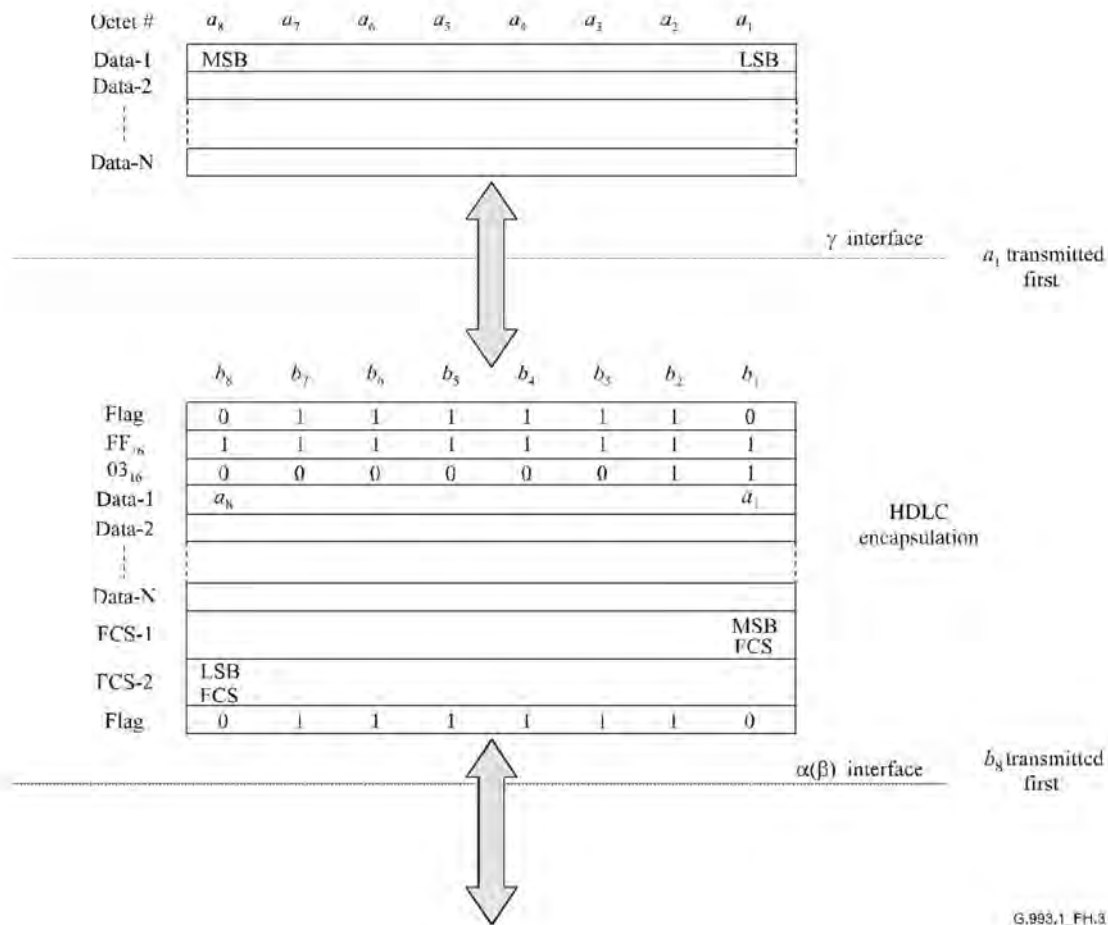


Figure H.3/G.993.1 – PTM-TC data flow

#### H.4.1.2 Octet transparency

To prevent failures due to false frame synchronization, any octet inside the PTM-TC frame that is equal to hexadecimal  $7E_{16}$  (the Flag Sequence) or hexadecimal  $7D_{16}$  (the Control Escape) shall be escaped as described below.

After FCS computation, the transmitter examines the entire frame between the opening and the closing Flag Sequences. Any data octets which are equal to the Flag Sequence or the Control Escape shall be replaced by a two-octet sequence consisting of the Control Escape octet followed by the original octet exclusive-OR'ed with hexadecimal  $20_{16}$ . In summary, the following substitutions shall be made:

- any data octet of  $7E_{16}$  – encoded as two octets  $7D_{16}$ ,  $5E_{16}$ .
- any data octet of  $7D_{16}$  – encoded as two octets  $7D_{16}$ ,  $5D_{16}$ .



On reception, prior to FCS computation, each Control Escape octet shall be removed, and the following octet shall be exclusive-OR'ed with hexadecimal  $20_{16}$  (unless the following octet is  $7E_{16}$ , which is the flag, and indicates the end of frame, and therefore an abort has occurred). In summary, the following substitutions are made:

- any sequence of  $7D_{16}$ ,  $5E_{16}$  – replaced by the data octet  $7E_{16}$ .
- any sequence of  $7D_{16}$ ,  $5D_{16}$  – replaced by the data octet  $7D_{16}$ .
- a sequence of  $7D_{16}$ ,  $7E_{16}$  aborts the frame.

NOTE – Since octet stuffing is used, the PTM-TC frame is guaranteed to have an integer number of octets.

#### H.4.1.3 Frame check sequence

The FCS shall be calculated over all bits of the address, control, and information fields of the PTM-TC frame as defined in ISO/IEC 3309, i.e., it shall be the one's complement of the sum (modulo 2) of:

- the remainder of  $x^k(x^{15} + x^{14} + x^{13} + x^{12} + x^{11} + x^{10} + x^9 + x^8 + x^7 + x^6 + x^5 + x^4 + x^3 + x^2 + x + 1)$  divided (modulo 2) by the generator polynomial  $x^{16} + x^{12} + x^5 + 1$ , where  $k$  is the number of bits in the frame existing between, but not including, the last bit of the opening flag and the first bit of the FCS, excluding octets inserted for transparency (H.4.1.2); and
- the remainder of the division (modulo 2) by the generator polynomial  $x^{16} + x^{12} + x^5 + 1$ , of the product of  $x^{16}$  by the content of the frame existing between, but not including, the last bit of the opening flag and the first bit of the FCS, excluding octets inserted for transparency.

The FCS is 16 bits (2 octets) in length and occupies fields FCS-1, FCS-2 of the PTM-TC frame. The FCS shall be mapped into the frame so that bit  $a_1$  ( $b_8$ ) of FCS-1 shall be the MSB of the calculated FCS, and bit  $a_8$  ( $b_1$ ) of the FCS-2 shall be the LSB of the calculated FCS (Figure H.3).

The register used to calculate the FCS at the transmitter shall be initialized to the value  $FFFF_{16}$ .

NOTE – As a typical implementation at the transmitter, the initial content of the register of the device computing the remainder of the division is preset to all binary ONES and is then modified by division by the generator polynomial, as described above, on the information field. The one's complement of the resulting remainder is transmitted as the 16-bit FCS. As a typical implementation at the receiver, the initial content of the register of the device computing the remainder of the division is preset to all binary ONES. The final remainder, after multiplication by  $x^{16}$  and then division (modulo 2) by the generator polynomial  $x^{16} + x^{12} + x^5 + 1$  of the serial incoming protected bits after removal of the transparency octets and the FCS, will be  $0001110100001111_2$  ( $x^{15}$  through  $x^0$ , respectively) in the absence of transmission errors.

#### H.4.2 Packet error monitoring

Packet error monitoring includes detection of invalid and errored frames at the receive side.

##### H.4.2.1 Invalid frames

The following conditions result in an invalid frame:

- Frames which are less than 5 octets in between flags not including transparency octets (Flag Sequence and Control Escape). These frames shall be discarded.
- Frames which contain a Control Escape octet followed immediately by a Flag (i.e.,  $7D_{16}$  followed by  $7E_{16}$ ). These frames shall be passed across the  $\gamma$  interface to the PTM entity.
- Frames which contain control escape sequences other than  $7D_{16}$ ,  $5E_{16}$  and  $7D_{16}$ ,  $5D_{16}$ . These frames shall be passed across the  $\gamma$  interface to the PTM entity.

All invalid frames shall not be counted as FCS errors. The receiver shall immediately start looking for the opening flag of a subsequent frame upon detection of an invalid frame. A corresponding receive error message (Rx\_Err – see H.3.1.2) shall be sent across the  $\gamma$  interface to the PTM entity.

#### **H.4.2.2 Errored frames**

A received frame shall be qualified as an errored frame (FCS-errored) if the CRC calculation result for this frame is different from the one described in H.4.1.3. Errored frames shall be passed across the  $\gamma$  interface. A corresponding receive error message (Rx\_Err – see H.3.1.2) shall be sent across the  $\gamma$  interface to the PTM entity.

#### **H.4.3 Data rate decoupling**

Data rate decoupling is accomplished by filling the time gaps between transmitted PTM-TC frames with additional Flag Sequences ( $7E_{16}$ ). Additional Flag Sequences shall be inserted at the transmit side between the closing Flag Sequence of the last transmitted PTM-TC frame and the subsequent opening Flag Sequence of the next PTM-TC frame, and discarded at the receive side respectively.

##### **H.4.3.1 Frame delineation**

The PTM-TC frames should be delineated by detecting of Flag Sequences. The incoming stream is examined on an octet-by-octet basis for the value of hexadecimal  $7E_{16}$ . Two (or more) consecutive Flag Sequences constitute an empty frame (frames), which shall be discarded, and not counted as a FCS error.

## **Annex I**

### **Specifics of implementation in systems using QAM modulation**

For systems that implement this annex, all of this Recommendation is implemented with the following exceptions:

- I.1 replaces clause 8;
- I.2 replaces clause 9;
- I.3.1 redefines some terms in 10.5.1 and 10.5.2;
- I.3.2 replaces 10.6;
- I.3.3 redefines some terms in 7.2;
- I.3.4 redefines some terms in 10.3.2.4;
- I.4.1 replaces 12.3;
- I.4.2 and I.4.3 replaces 12.4;
- I.4.4 replaces 12.1 and 12.2;
- I.5 is an informative clause that presents supplemental information.

#### **I.1 Physical Media Specific TC (PMS-TC) sublayer**

##### **I.1.1 Functional model**

The PMS-TC sublayer functional model for both VTU-O and VTU-R is presented in Figure I.1. The PMS-TC sublayer includes functional blocks for randomization (Scrambler), forward error correction (FEC), interleaving, transmission frame encapsulation (MUX), and management. Both the Fast and the Slow channel have an application-independent format at the  $\alpha(\beta)$  interface. The transmission frame (see I.1.2, I.1.2.2) is multiplexed from the Slow data, Fast data, and a header. The header carries the NTR marker, Indicator Bits (IB), special flags for link activation, and a Syncword for frame alignment. The PMS-TC management provides all OAM primitives and parameters related to the PMS-TC.



Transmit data of both the Fast and Slow channels incoming via the  $\alpha(\beta)$  interface is randomized, protected by FEC, and multiplexed into the transmission frame. Slow channel protection includes interleaving. The PMS-TC provides a dual latency mode if both the Fast and Slow channels are implemented. It provides a single latency mode if only the Slow channel is implemented. The latency mode can be different in different transmission directions. The transport class of the transmission frame (see I.1.2.3) determines the latency mode and transport capability of both channels at the I\_O (I\_R) reference point. It shall be set during the system configuration.

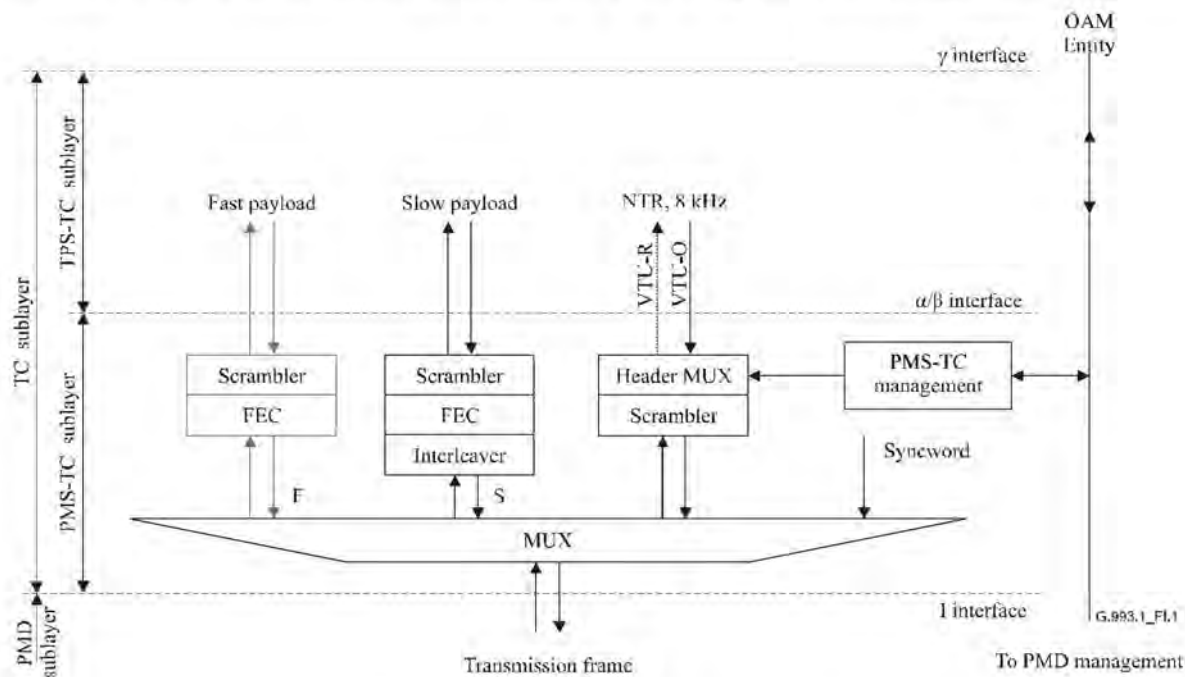


Figure I.1/G.993.1 – PMS-TC functional model

## I.1.2 Transmission frame

### I.1.2.1 Frame format

The same format of the transmission frame, as shown in Figure I.2, shall be applied in both the upstream and downstream directions. The frame shall contain 405 octets: a 5-octet header and a 400-octet payload. The frame payload shall include two equal fields for the Fast channel ( $F$  octets each) and two equal fields for the Slow channel ( $S$  octets each). Slow and Fast fields shall alternate, as shown in Figure I.2.

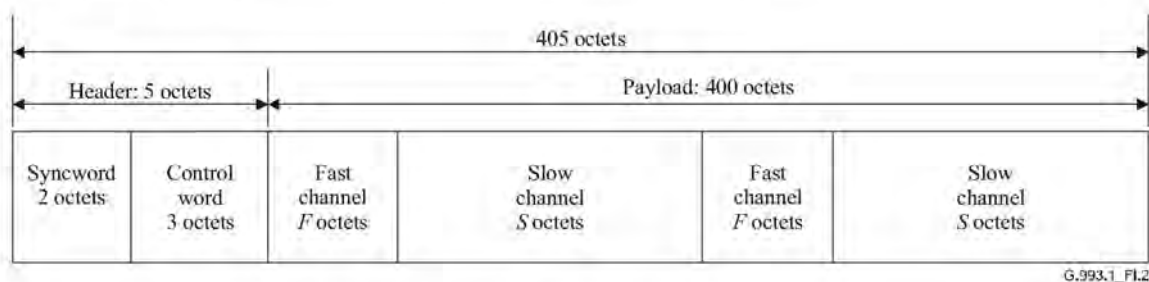


Figure I.2/G.993.1 – Transmission frame format



Each Fast channel field transports one Reed-Solomon (RS) codeword with no interleaving (Fast codeword). Each Slow channel field transports one RS codeword (Slow codeword), which shall pass through an interleaver (see I.1.2.8) before transmission onto the line. Both  $F$  and  $S$  values shall be even, and shall comply with the applied transport class (Table I.5). Fast channel is optional. If not used,  $F = 0$ .

All frame octets are transmitted with MSB first. The MSB of the first transmitted frame octet corresponds to the beginning of the frame.

NOTE – The appropriate transport class should be specified during the system configuration prior to steady state transmission.

#### I.1.2.1.1 Fast codeword

The structure of the Fast codeword shall be as shown in Figure I.3. The codeword shall consist of a Fast Payload field of  $PF$  octets and Fast FEC field of  $RF$  octets. The length of the Fast codeword may be 0-180 octets. The value of  $RF$  octets may be 0, 2, 4 or 16 octets. Non-zero values of  $PF$  and  $RF$  are optional; the valid non-zero values for class 2 frame (dual latency) are presented in Table I.5. The first octet of the Fast codeword in Figure I.3 shall correspond to the first octet of the Fast Payload shown in Figure I.2.

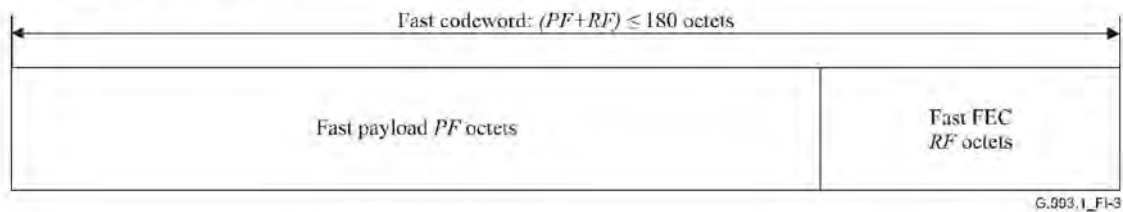


Figure I.3/G.993.1 – Fast codeword

NOTE 1 – The value  $RF = 0$  provides uncoded data transmission over the Fast channel.

NOTE 2 – For an uncoded implementation of the Fast channel, the standard method of verification of the error monitoring procedure described in I.1.2.7 is not applicable. The verification method in this case is left to be done by means of the relevant TPS-TC or by means of the application.

#### I.1.2.1.2 Slow codeword

The structure of a Slow codeword (prior to interleaving) shall be as shown in Figure I.4. The codeword shall consist of a 3-octet Operations Channel (OC) field, a Slow Payload field of  $PS$  octets, and a Slow FEC field of 16 octets. The length of the Slow codeword may be 20-200 octets. For a class-1 frame (single latency),  $S = 200$ . The valid values of  $S$  for class 2 frame (dual latency) may be derived from Table I.5. The first octet of the Slow codeword in Figure I.4 shall correspond to the first octet of the OC shown in Figure I.5.

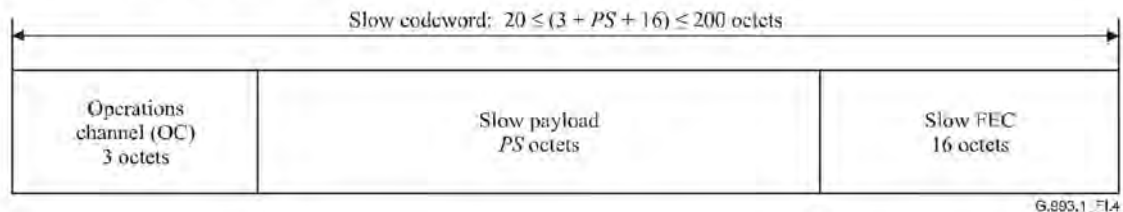
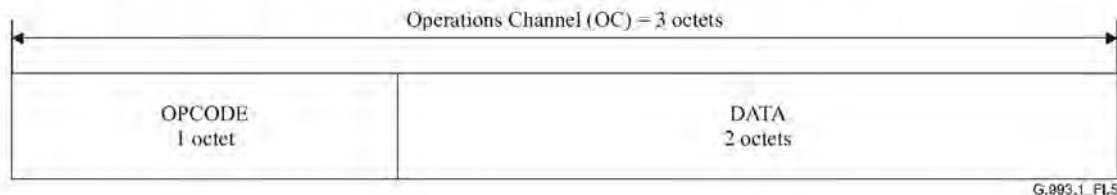


Figure I.4/G.993.1 – Slow codeword

The structure of the OC field shall be as shown in Figure I.5. The first OC octet shall be reserved for OC OPCODE, the second and third shall be for OC data.

NOTE – The OC is shared between the embedded operations channel (eoc) and the VDSL Overhead Control (VOC) channel as described in I.3.3.



**Figure I.5/G.993.1 – Operations channel field**

#### **I.1.2.2 Frame header**

The transmission frame header includes a 2-octet Syncword and a 3-octet Control field. The Syncword contains frame alignment information. The Control field conveys management and auxiliary information as described in Tables I.2 to I.4, including four bits reserved for proprietary use. A 4-bit cyclic redundancy check (CRC) incorporated into the Control field allows error detection in the received data. The header is described in Table I.1. In all the following descriptions, bit #7 of any octet is MSB. Bit #7 of octet #0 shall be transmitted first.

**Table I.1/G.993.1 – Allocation of octets in frame header**

Octet	Name	Description	Value
0	Sync 1	Syncword, octet 1	0xF6
1	Sync 2	Syncword, octet 2	0x28
2	Control 1	Control and Management information, octet 1	Variable
3	Control 2	Control and Management information, octet 2	
4	Control 3	Control and Management information, octet 3	

NOTE – Here and further, "0x" is used as a placeholder for "hexadecimal".

##### **I.1.2.2.1 Syncword octets**

The same Syncword shall be used in both transmission directions. The Syncword shall consist of two octets with the values: Sync 1 = 0xF6, Sync 2 = 0x28.

##### **I.1.2.2.2 Control 1 octet**

The Control 1 octet shall contain the *NTR*-bit, the *o/r\_trig* and *o/r\_flag* bits, used for the link activation support, and the first five indicator bits (IB-1 through IB-5) intended for far-end monitoring, as described in Table I.2. All IB shall be coded "0" for normal operation and "1" for abnormal operation (defect or failure condition).



**Table I.2/G.993.1 – Control 1 octet**

Bit	Name	Description	Value	Note
7	<i>trig</i>	"o_trig" signal in downstream direction "r_trig" signal in upstream direction	"0" for normal state "1" for the active state	See I.4
6	<i>flag</i>	"o_flag" signal in downstream direction "r_flag" signal in upstream direction		
5	IB-1 ( <i>fp_1</i> )	Far-end TPS_TC #1 defect/failure	"0" for normal state "1" for the TPS-TC failure	
4	IB-2 ( <i>fp_2</i> )	Far-end TPS_TC #2 defect/failure		
3	IB-3 ( <i>fp_3</i> )	Far-end TPS_TC #3 defect/failure		
2	IB-4 ( <i>fp_4</i> )	Far-end TPS_TC #4 defect/failure		
1	IB-5 (Reserved)	For additional defects/failures	"0" for normal state "1" for the failure state	
0	<i>NTR</i>	NTR marker	"1" if NTR marker is transmitted, "0" otherwise	See I.1.2.4

Far-end path indicators (*fp*) shall be used for path-related primitives of possible paths numbered from #1 to #4. Additional paths can be indicated using bit 1 of the Control 1 octet and bits 1, 2 of the Control 2 octet. The definition of the *fp* shall coincide with the definition of the corresponding path-related primitive. If only one type of service is applied, the *fp\_1* shall be used to indicate the failure of the Slow channel TPS-TC, and the *fp\_2* shall be used to indicate the failure of the Fast channel TPS-TC.

For the ATM path, *fp* shall indicate the *Far-end Loss of Cell Delineation (fled)* defect, as it is defined in 10.5.2.1.

For the PTM-TC, *fp* shall indicate the *FPER* defect, as it is defined in 10.5.2.3.

As an example, if ATM is the only service, the *fp\_1* shall be used to indicate the *fled* defect for the Slow ATM-TC, and the *fp\_2* shall be used to indicate the *fled* defect for the Fast ATM-TC, if applicable.

#### **I.1.2.2.3 Control 2 octet**

The Control 2 octet shall contain the first and second CRC bits, and the IB bits IB-6 through IB-11, as presented in Table I.3. All IB shall be coded "0" for normal operation and "1" for abnormal operation (defect or failure condition). The *CRC\_1* and *CRC\_2* bits shall be assigned as described in I.1.2.2.5.

**Table I.3/G.993.1 – Control 2 octet**

Bit	Name	Description	Value	Note
7	<i>CRC_1</i>	Frame header CRC check	First bit	See I.1.2.2.5
6	IB-6 (Reserved)	IB for future applications	"0" for normal state "1" for the failure state	

**Table I.3/G.993.1 – Control 2 octet**

Bit	Name	Description	Value	Note
5	IB-7 ( <i>flos_cr1</i> )	Far-end loss of energy – Carrier 1	"0" for normal state "1" for the loss state	PMD, PMS-TC primitives; see I.3.1 and 10.5
4	IB-8 ( <i>flos_cr2</i> )	Far-end loss of energy – Carrier 2		
3	IB-9 ( <i>rdi</i> )	Far-end severely errored frame defect	"0" for normal state "1" for the failure state	
2	IB-10 (Reserved)	IB for future applications	"0" for normal state "1" for the failure state	
1	IB-11 (Reserved)	IB for future applications	"0" for normal state "1" for the failure state	
0	<i>CRC_2</i>	Frame header CRC check	Second bit	See I.1.2.2.5

**I.1.2.2.4 Control 3 octet**

The Control 3 octet shall contain the third and the fourth *CRC* bits, two IB bits (IB-12, IB-13), and four bits for proprietary use, as presented in Table I.4. All IB shall be coded "0" for normal operation, and "1" for abnormal operation (defect or failure condition). The *CRC\_3* and *CRC\_4* bits shall be assigned as described in I.1.2.2.5.

**Table I.4/G.993.1 – Control 3 octet**

Bit	Name	Description	Value	Note
7	<i>CRC_3</i>	Frame header CRC check	Third bit	See I.1.2.2.5
6	IB-12 ( <i>FPO</i> )	Far-end power-off failure	"0" for normal state "1" for the power failure state	Power related primitives; see I.3.1 and 10.5.3.
5	IB-13 ( <i>flpr</i> )	Far-end loss-of-power defect ("dying gasp")		
4-1	Reserved	For proprietary applications	"0" for normal state "1" for the failure state	
0	<i>CRC_4</i>	Frame header CRC check	Fourth bit	See I.1.2.2.5

**I.1.2.2.5 CRC-bits**

The *CRC* bits *CRC\_1* ÷ *CRC\_4* are computed by multiplying the polynomial

$$m_0D^{23} + m_1D^{22} + \dots + m_{23} \text{ by } D^4$$

dividing by  $D^4 + D + 1$ , and taking the remainder.

The polynomial coefficient  $m_0$  shall be the MSB of the first Control 1 octet,  $m_{23}$  shall be the LSB of Control 3 octet, and  $m_8, m_{15}, m_{16}, m_{23} = 0$ . The *CRC\_1* shall be the MSB of the remainder; the *CRC\_4* shall be the LSB of the remainder.

**I.1.2.3 Frame transport classes**

The transmission frame transport class defines the number of *S*, *F*, and *RF* octets in the transmission frame. The mandatory class 1 provides single latency transport. The optional class 2 provides dual latency transport.



A class 1 frame shall include two Slow codewords of 200 octets each. A class 2 frame shall include both Slow and Fast codewords. The format of class 2 frame is defined by the values of  $F$  and  $RF$ , and denoted as  $[F/RF]$ , where  $RF$  can be 0, 2, 4 or 16, and  $F$  is even between 2 and 180. In the same manner, class 1 frame is denoted as  $[0/0]$ .

NOTE 1 – A class 2 frame denoted  $[12/8]$ , for example, defines a frame that contains a Fast codeword with 4 Fast Payload octets, 8 Fast FEC octets and a Slow codeword with  $200 - 12 = 188$  octets (three OC octets, 169 Slow Payload octets and 16 Slow FEC octets, Figure I.4).

NOTE 2 – The possible settings of  $F$  are limited to those which result in relevant settings of  $S = 200 - F$  for the selected configuration of the interleaver (value  $S/I$ ), as specified in I.1.2.8.

The frame definition of class 1 and class 2 is summarized in Table I.5. The calculation of the aggregate transport capability of the frame of the particular class is presented in I.5.2.

**Table I.5/G.993.1 – Frame transport classes**

Class	Slow Data $S$ , octets	Fast Data $F$ , octets	Fast Redundancy $RF$ , octets	Symbol	Mode	Notes
1	200	0	0	$[0/0]$	Single latency	Mandatory
2	$200 - F$	$F = 2 - 180$	$RF = 0, 2, 4, 16$	$[F/RF]$	Dual latency	Optional

#### **I.1.2.4 NTR transport and NTR marker generation**

An 8-kHz NTR is conveyed from the VTU-O to VTU-R by synchronizing the downstream transmission frame boundaries with NTR and transmitting an NTR marker in the frame header, as described in I.1.2.2. The NTR is reconstructed at the VTU-R using the received NTR marker.

An NTR marker for the transmission profile with a bit rate of  $N \times 33.75$  kbit/s shall be generated every  $768/Q$  NTR periods (i.e., every  $96/Q$  ms the NTR marker will transition from low to high level), where  $Q$  is the greatest common divisor of 768 and  $N$ .

NOTE – As follows from the definition above, the NTR marker will be set to 1 every  $N/Q$  transmission frames. For example, assume  $N = 96$  ( $TR = 3.24$  Mbit/s). Then  $Q = \text{gcd}(768, 96) = 96$ , and  $96/Q = 1$ . Accordingly, the NTR marker bit will be set to 1 every 1 ms. The number of transmission frames between two adjacent NTR markers equals 1, and the number of NTR periods between two adjacent NTR markers equals 8.

#### **I.1.2.5 Frame delineation algorithm**

The delineation algorithm for the transmission frame shall be left to the discretion of the implementers. The recommended algorithm is based on Syncword detection at the expected locations (i.e., on Sync\_Events as described in I.5.3).

#### **I.1.2.6 Randomization and de-randomization**

Randomization shall be performed in both transmission directions by the same randomization algorithm prior to RS encoding. Data de-randomization shall be performed after RS decoding. Randomization/de-randomization shall be performed on the frame header, except for Sync1 and Sync2 octets, and on the frame payload, except for the RS redundancy octets. The header, Fast codewords and Slow codewords transmitted in the same direction shall be randomized separately by the same randomization algorithm.

The randomization algorithm in both the VTU-O and VTU-R shall be:

$$D_{out}^n = D_{in}^n \oplus D_{out}^{n-18} \oplus D_{out}^{n-23}$$

The de-randomization algorithm shall reconstruct the randomized data. The block diagram of the randomizer is presented in Figure I.6.



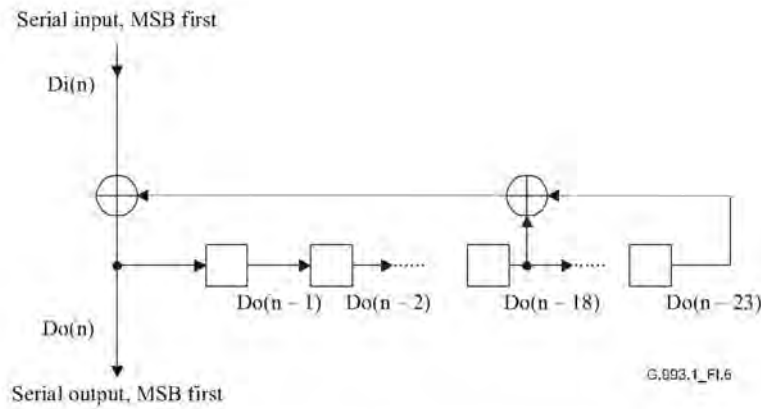


Figure I.6/G.993.1 – Randomizer

NOTE – Both the randomizer and de-randomizer are self-synchronizing.

#### I.1.2.7 Forward error correction

Reed-Solomon (RS) coding shall be used for forward error correction (FEC). The applied code  $RS(N,K)$  is expressed by the total codeword length in octets ( $N$ ) and the number of data octets ( $K$ ). The difference  $(N - K)$  is the number of FEC octets (redundancy octets).

NOTE 1 – The error correcting power of the RS code is related to the number of FEC octets  $(N - K)$ . The number of corrected octets  $t$  per codeword equals  $\lfloor (N - K)/2 \rfloor$ , where  $\lfloor X \rfloor$  denotes truncating  $X$  to the lower integer.

NOTE 2 – The actual values of  $N$  and  $K$  in  $RS(N,K)$  are  $(OC + PS + 16, OC + PS)$  for the Slow codeword and to  $(PF + RF, PF)$  for the Fast codeword (see Figures I.3 and I.4, respectively).

The RS codes applied for downstream and upstream shall use the generator polynomial:

$$g(x) = \prod_{i=0}^{N-K-1} (x + \mu^i)$$

where  $\mu$  is a root of the binary primitive polynomial:

$$x^8 + x^4 + x^3 + x^2 + 1$$

A data octet shall be identified within the Galois Field (256) of 256 elements as:

$$(d_7 d_6 d_5 d_4 d_3 d_2 d_1 d_0) \sum_{n=0}^7 d_n \mu^n \Leftrightarrow \mu^p \quad (\mu = 02\text{hex})$$

with a one-to-one mapping of octet values ( $d_0$  remains the LSB,  $d_7$  remains the MSB; the MSB shall be transmitted first).

An  $RS(N,K)$  codeword shall be a function of the  $K$  data octets as:

$$\left[ x^{N-K} \left( \sum_{i=0}^{K-1} \mu^{p(i)} x^i \right) \right] + \left[ x^{N-K} \left( \sum_{i=0}^{K-1} \mu^{p(i)} x^i \right) \right] \text{MOD} g(x)$$

where the  $K$  most significant octets (coefficients of  $x^n$ ,  $n = N - K..N - 1$ ) correspond to the  $K$  input data octets, and the  $N - K$  least significant octets (coefficients of  $x^n$ ,  $n = 0..N - K - 1$ ) correspond to the  $N - K$  output FEC octets.

The RS( $N, K$ ) encoding/decoding shall be implemented as a shortened RS(255,  $255 - N + K$ ) code. At the encoder side,  $(255 - N)$  octets, all set to 0, shall be appended before the  $K$  data octets at the input of the RS(255,  $255 - N + K$ ) encoder. These appended octets shall be discarded after the encoding procedure.

It shall be possible to introduce intentional corruption into RS codeword for error monitoring verification purposes. A corruption shall be introduced upon the appropriate request from the management system (see 10) into a single octet of the FEC redundancy field of either the Slow or the Fast channel.

#### **1.1.2.8 Interleaving**

Slow codewords of the transmission frame shall be interleaved before transmission by a convolutional interleaver. The latter is defined by the following parameters:

$S$ : Incoming codeword length defined by the transmission frame format, Table I.5;

$I$ : Interleaver block length, octets;

$D$ : Interleaving depth, octets;

$M$ : Interleaving depth index.

The interleaver shall function as follows. The incoming codeword of  $S$  octets shall be divided into blocks of  $I$  octets. The nominal block length  $I$  shall be  $S/8$ . Optionally, it may equal to  $S/16$ ,  $S/4$  or  $S/2$ . The particular value of  $I$  is set during the initialization as specified in 1.3.2.1.1.8. The octets within the interleaver blocks shall be numbered from  $j = 0$  to  $j = I - 1$ . Each octet  $j$  of any block shall be delayed at the interleaver output by  $(D - 1) \times j$  octets, where  $j = 0, 1, 2, \dots (I - 1)$  is the octet number within the block and  $D$  is the interleaving depth. For example, the first octet of any block shall not be delayed. The third octet of any block shall be delayed by  $2 \times (D - 1)$  octets, and so on. The value of  $(D - 1)$  shall be a multiple of the interleaver block length  $I$ :

$$D = M \times I + 1$$

where  $M$  is an integer. The value of  $M$  shall be programmable to any integer in the range of 0 to 64. The actual values of  $I$  and  $M$  should be set prior to the link initialization.

The main characteristics of the interleaver and an example of interleaver and de-interleaver implementation are presented in I.5.4.

The value  $D - 1$  characterizes the number of octets separating any two sequential octets of the same RS codeword after interleaving. It should be chosen in accordance with the required impulse noise protection and latency requirements. Setting  $M = 0$  cancels interleaving.

NOTE – The specified range of values for  $M$  allows erasure correction capability up to 500  $\mu$ s for all transmission data rates below 26 Mbit/s as shown in I.5.4.

## **1.2 Physical medium-dependent (PMD) sublayer**

### **1.2.1 PMD functional model**

The PMD sublayer functional model is presented in Figure I.7. The model defines VDSL transceiver functionality between the I\_O (I\_R) and U<sub>2</sub>\_O (U<sub>2</sub>\_R) reference points, respectively.

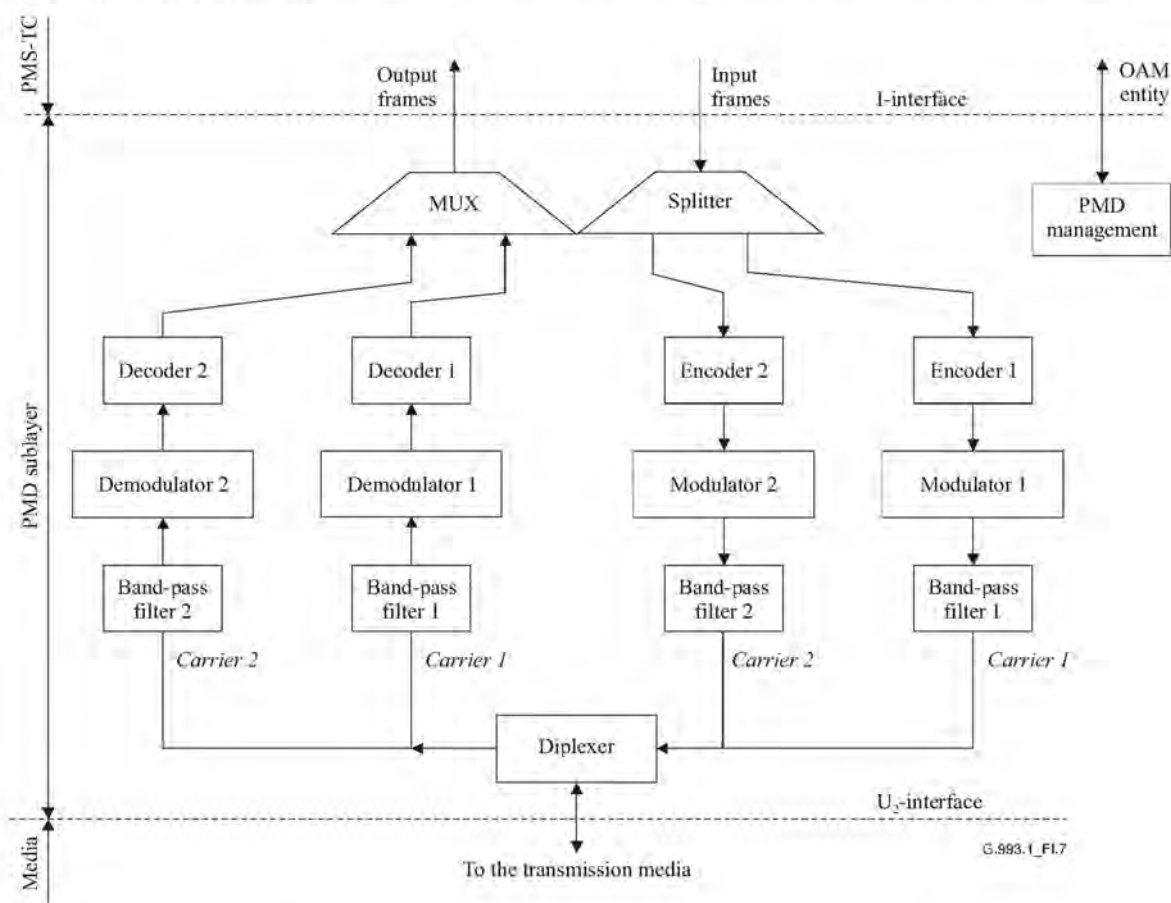
In the transmit direction, the input frame (see I.1.2) coming from the PMS-TC via the I-interface is split into two streams. Each stream is encoded, modulated, and sent onto the transmission line via the U<sub>2</sub>-interface. Each stream is transmitted in one of the frequency bands specified in 6.1, separated by the band-pass filter. The signal transmitted in a particular band is called a carrier.

Four possible carriers: 1D (carrier 1, downstream), 2D (carrier 2, downstream), 1U (carrier 1, upstream), and 2U (carrier 2, upstream) can be used; up to two carriers can be transmitted in the



same direction. If the first carrier can transmit all the input data, the usage of the second carrier is optional. In that case, both the splitter and multiplexer are bypassed.

NOTE – The name of the carrier is not associated with any particular frequency band. If the optional frequency band or any later specified additional band is used, the name of the carrier using this band will be one of those already defined.



**Figure I.7/G.993.1 – VTU PMD sublayer functional model**

The band-pass filters restrict the transmit out-of-band power to prevent crosstalk between the upstream and downstream carriers. The diplexer provides additional decoupling between transmit and receive signals.

In the receive direction, the carriers received in both bands are demodulated, decoded and multiplexed into the output frame, which has the same structure as the input frame. The output frame is sent to the PMS-TC via the I-interface.

The PMD management block is responsible for all the OAM functions corresponding with PMD. The exchange of management information between the PMD management block and the OAM entity is accomplished via the I-interface.

## **1.2.2 Transmitter functionality**

### **1.2.2.1 Splitting**

The same splitting procedure shall be used in both the upstream and downstream directions. The splitter shall originate a PMD-frame for both transmitted carriers to compensate for the difference in

propagation delay between the two carriers at the receive side. The PMD-frame format shall consist of 405 octets: a 2-octet Syncword for frame alignment followed by a 403-octet data field. The PMD-frame Syncword shall be the same as specified in I.1.2.2.1 for the transmission frame (contains Sync1, Sync2 octets).

The PMD-frame structure and splitting procedure of the input frame are described in Figure I.8. The splitter maps the input frame into two PMD-frames with data rate ratio of  $N1/N2$ , where  $N1$ ,  $N2$  are integers. The splitting cycle shall start from the frame alignment octet Sync1 of any input frame (input frame #1 in Figure I.8). The Sync1 octet and the following Sync2 octet from input frame #1 shall be sent into both carrier 1 and carrier 2 to arrange their own Syncwords. Further, the  $N1$  octets of input frame #1 following Sync2 octet shall be mapped into carrier 1, and the  $N2$  following octets of the input frame #1 shall be mapped into carrier 2. A repetition of this process over subsequent input frames forms the information field of the PMD frame. An inverted Syncword shall be inserted into each PMD frame after every 403 data octets inserted into its information field. If fewer than  $N1$  or  $N2$  octet positions remain at the end of a given PMD frame, the next group of  $N1$  or  $N2$  octets, respectively, shall be split in the corresponding PMD frame by an inverted Syncword, as shown in Figure I.8.

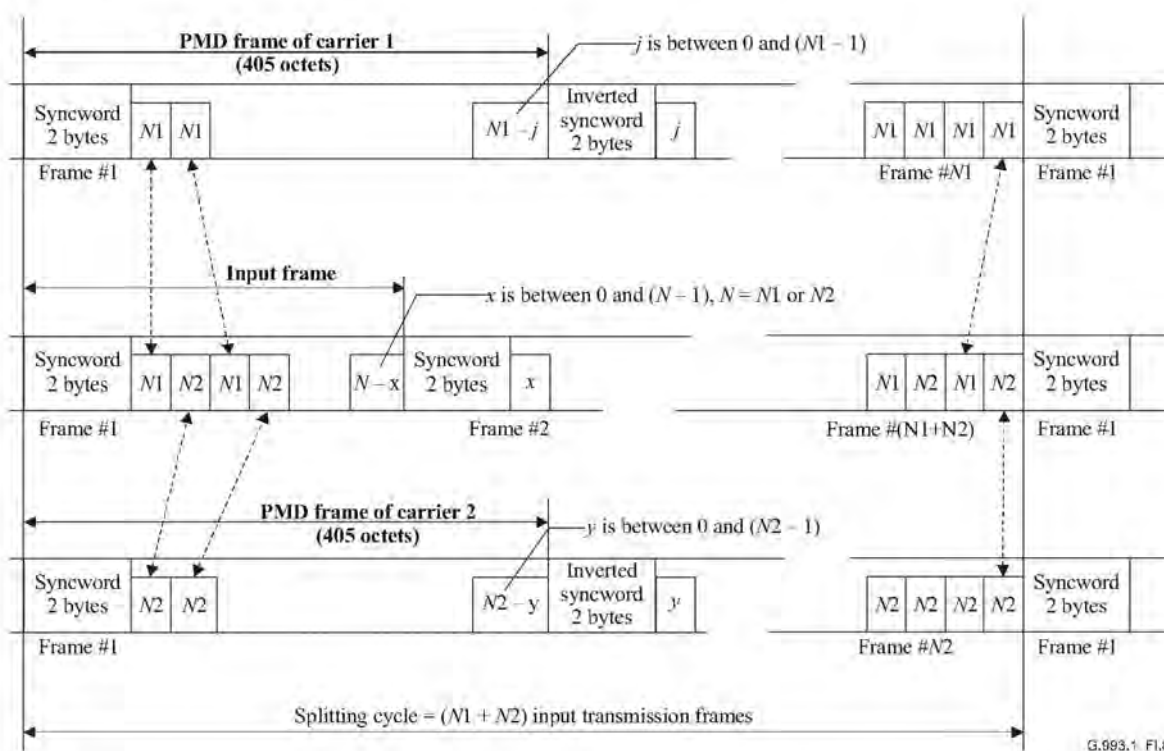


Figure I.8/G.993.1 – PMD-frame format

The splitting process is cyclic. A cycle contains  $(N1 + N2)$  input frames. During the splitting cycle exactly  $N1$  frames are mapped into carrier 1 and exactly  $N2$  frames are mapped into carrier 2.

NOTE – For the given bit rates  $DR1$  and  $DR2$  of carrier 1 and carrier 2, respectively, with a greatest common divisor  $g = \text{gcd}(DR1, DR2)$ , the values of  $N1$ ,  $N2$  will be:  $N1 = DR1/g$ ,  $N2 = DR2/g$ .

The time difference between the beginnings of the splitting cycles of the PMD frames transmitted by carrier 1 and carrier 2, measured at the output of the transceiver, shall be less than  $\max\{40 \times \text{abs}(T1 - T2) + 5, 20\} \mu\text{s}$ , where  $T1 = 1/SR1$ ,  $T2 = 1/SR2$ ,  $SR1$ ,  $SR2$  are symbol rates of



carrier 1 and carrier 2, respectively. The timing difference should be measured with respect to the start of the first bit of the PMD frame starting the splitting cycle for each carrier.

### 1.2.2.2 Timing

Transmitters of both carriers in the VTU-O shall use a transmit clock derived from the network clock (e.g., SONET clock, SDH clock, PON clock) to allow end-to-end network synchronization. If the network clock is not available, the VTU-O shall use a locally generated master clock with a maximum tolerance of  $\pm 50$  ppm.

Transmitters of both carriers in the VTU-R shall use a transmit clock derived from the received data clock of either the first or the second downstream carrier (loop timing). If the received data clock is lost during steady-state transmission, the VTU-R shall use a locally generated clock with a maximum tolerance of  $\pm 50$  ppm to perform the link activation.

### 1.2.2.3 Coding and modulation

The transmission capability and timing between the VTU-O and the VTU-R in both transmission directions shall be provided by using Quadrature Amplitude Modulation (QAM). The coding and modulation functionality of the transceiver is described in Figure I.9. The input data stream shall be encoded into two symbol streams  $I_n$  and  $Q_n$ , where  $n$  designates the  $n$ th symbol period. The symbol streams  $I_n$  and  $Q_n$  shall be modulated and sent into the transmission media via the band-pass filter.

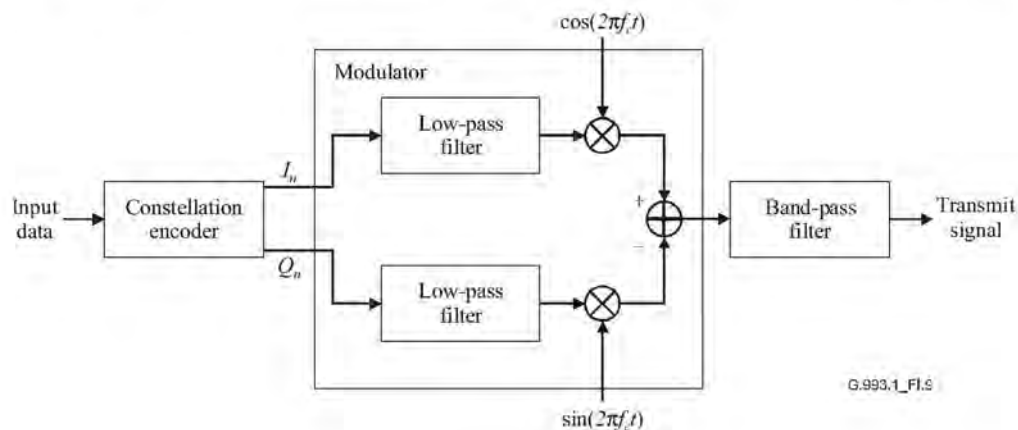


Figure I.9/G.993.1 – Block diagram of a SCM transmitter

#### 1.2.2.3.1 Constellation encoder

The encoding procedure shall treat the input data as a serial stream of bits with the most significant bit first. For a given constellation of size  $2^M$ , a group of  $M$  consecutive bits  $\{b_1, b_2, \dots, b_M\}$  of the input data shall be encoded into one symbol, and consecutive groups of  $M$  bits are encoded into consecutive symbols as illustrated in Figure I.10. Differential quadrant encoding shall be used. For  $M=1$ , every input bit shall be encoded as specified in the upper part of Table I.6. The two possible values of  $\{b_1\}$  represent the transition of the symbol between first and third quadrants. For  $M>1$ , the first two bits  $\{b_1, b_2\}$  shall be encoded as described in Table I.6. The four values of  $\{b_1, b_2\}$  represent the quadrant transition of the symbols, Figure I.11. The remaining  $(M-2)$  bits shall be encoded in accordance with the relevant constellation diagrams.



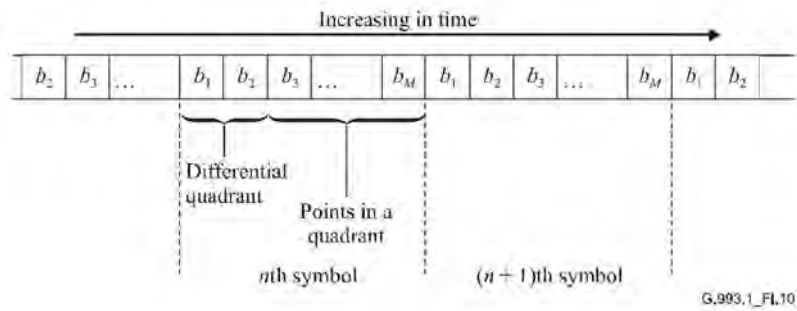


Figure I.10/G.993.1 – Bit to symbol mapping

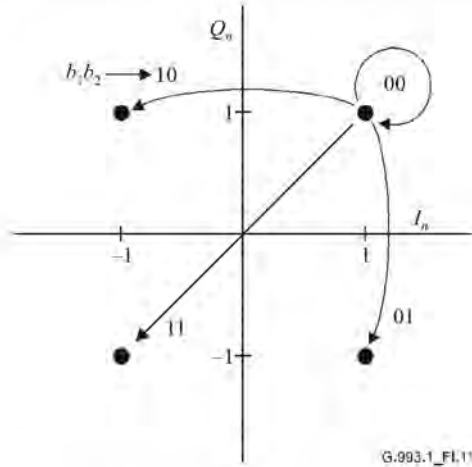


Figure I.11/G.993.1 – 4-point constellation with differential bit encoding

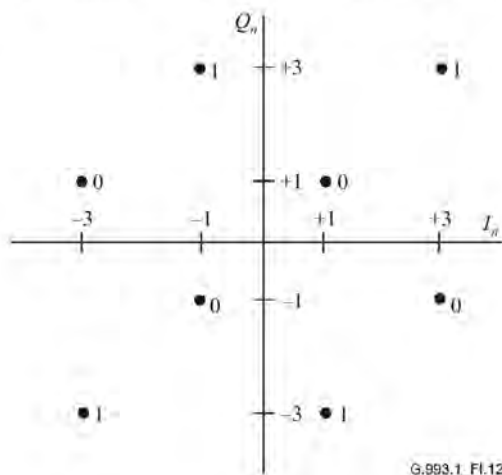
Table I.6/G.993.1 – Differential encoding of  $b_1$  and  $\{b_1 b_2\}$ 

$\{b_1\}$ , or $\{b_1\ b_2\}$	Previous quadrant number	Sign of previous symbol	Current quadrant number	Sign of current symbol
		$I_{n-1}\ Q_{n-1}$		$I_n\ Q_n$
$M=1$ (QAM-2)				
0	1st	+ +	1st	+ +
0	3rd	- -	3rd	- -
1	1st	+ +	3rd	- -
1	3rd	- -	1st	+ +
$M>1$ (QAM-4 and higher)				
00	1st	+ +	1st	+ +
00	2nd	- +	2nd	- +
00	3rd	- -	3rd	- -
00	4th	+ -	4th	+ -
01	1st	+ +	4th	+ -
01	2nd	- +	1st	+ +
01	3rd	- -	2nd	- +

**Table I.6/G.993.1 – Differential encoding of  $b_1$  and  $\{b_1 b_2\}$** 

$\{b_1\}$ , or $\{b_1 b_2\}$	Previous quadrant number	Sign of previous symbol	Current quadrant number	Sign of current symbol
		$I_{n-1} \quad Q_{n-1}$		$I_n \quad Q_n$
01	4th	+ –	3rd	– –
10	1st	+ +	2nd	– +
10	2nd	– +	3rd	– –
10	3rd	– –	4th	+ –
10	4th	+ –	1st	+ +
11	1st	+ +	3rd	– –
11	2nd	– +	4th	+ –
11	3rd	– –	1st	+ +
11	4th	+ –	2nd	– +

For a constellation diagram of 8 points, the encoding shall be as specified in Figure I.12.

**Figure I.12/G.993.1 – 8-point constellation and bit mapping**

For constellation diagrams of  $2^M$  points with even values of  $M$  between 4 and 12 (square constellations), the binary values of in-phase  $I_n$  and quadrature  $Q_n$  coordinates for the  $M - 2$  bit group  $\{b_3 \dots b_{M-2}\}$  in the first quadrant shall be as specified in Table I.7.

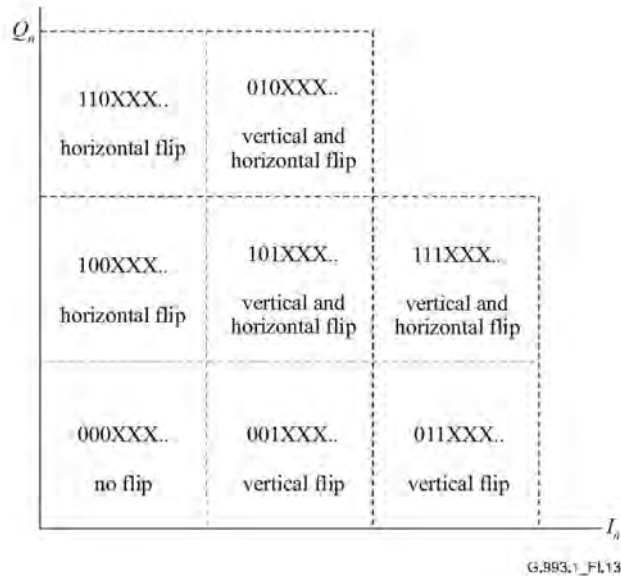
**Table I.7/G.993.1 – First quadrant encoding for even values of  $M$** 

$I_n$ (binary) = $[X_1 \ X_2 \ \dots \ X_{M/2-1} \ 1]$	$Q_n$ (binary) = $[Y_1 \ Y_2 \ \dots \ Y_{M/2-1} \ 1]$
$X_1 = b_3$	$Y_1 = b_{M/2+2}$
$X_2 = X_1 + b_4$	$Y_2 = Y_1 + b_{M/2+3}$
$X_3 = X_2 + b_5$	$Y_3 = Y_2 + b_{M/2+4}$
...	...
$X_{M/2-1} = X_{M/2-2} + b_{M/2+1}$	$Y_{M/2-1} = Y_{M/2-2} + b_M$

NOTE – The following example clarifies usage of Table I.7. For QAM-64 ( $M = 6$ ), and a group with the four last bits  $\{b_3b_4b_5b_6\} = 0001$ , we get  $X_1 = X_2 = 0$ ,  $Y_1 = 0$ ,  $Y_2 = 1$ , and  $I_n = 001$ ,  $Q_n = 011$ . Using decimal values we find that the constellation point with  $I_n = 1$  and  $Q_n = 3$  to be coded 0001.

For verification purposes, the first quadrant of the QAM-64 constellation diagram is presented in Figure I.14.

For constellation diagrams of  $2^M$  points with odd values of  $M$  between 5 and 11 (cross-shaped constellations) the encoding in the first quadrant shall be as follows. First, the quadrant shall be divided into 8 sections, as shown in Figure I.13, and each section shall be coded by a 3-bit section code using bits  $b_3b_4b_5$ .



**Figure I.13/G.993.1 – Mapping sections for constellations with odd values of  $M > 5$**

The rest of the bits (applicable for  $M > 5$  and those bits denoted "XXX" in Figure I.13) shall be mapped inside each section as specified in Table I.18. Further, the coded sections shall be flipped horizontally, vertically, or both, as shown in Figure I.13. For verification purposes, the first quadrant of QAM-128 constellation ( $M = 7$ ) is presented in Figure I.15.

**Table I.8/G.993.1 – First quadrant encoding for odd values of  $M > 5$**

$I_{n-sec}$ (binary) = $[X_1 X_2 \dots X_{(M-5)/2} 1]$	$Q_{n-sec}$ (binary) = $[Y_1 Y_2 \dots Y_{(M-5)/2} 1]$
$X_1 = b_6$	$Y_1 = b_{(M-5)/2+6}$
$X_2 = X_1 + b_7$	$Y_2 = Y_1 + b_{(M-5)/2+7}$
...	...
$X_{(M-5)/2} = X_{(M-5)/2-1} + b_{(M-5)/2+5}$	$Y_{(M-5)/2} = Y_{(M-5)/2-1} + b_M$

For all constellations with sizes more than 8 ( $M \geq 4$ ) the second, third and fourth quadrant mappings shall be derived from the mappings in the first quadrant by rotating the quadrant counter-clockwise by 90 degrees, 180 degrees, and 270 degrees, respectively.

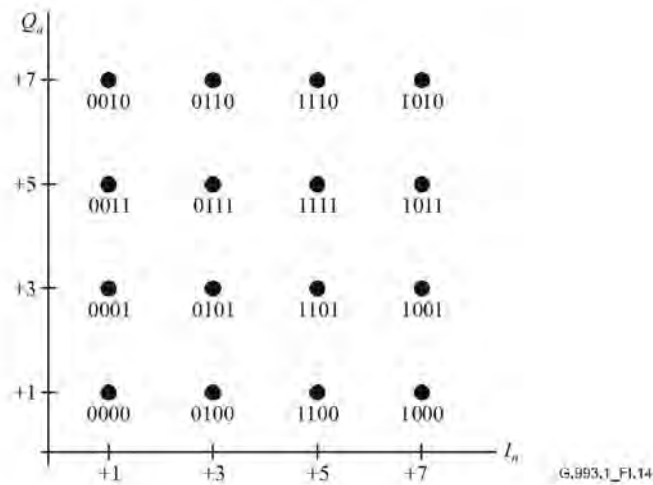


Figure I.14/G.993.1 – 64-point constellation and bit mapping (first quadrant)

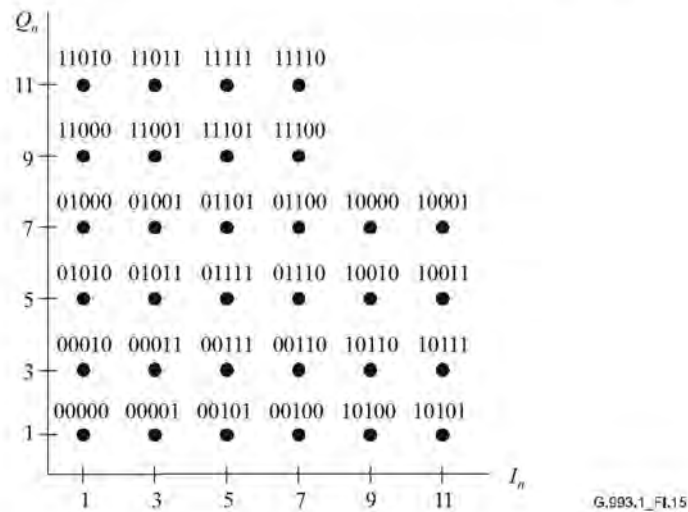


Figure I.15/G.993.1 – 128-point constellation and bit mapping (first quadrant)

### I.2.2.3.2 Modulator

The two encoded streams,  $I_n$  and  $Q_n$ , shall be sent to identical low-pass shaping filters (see Figure I.9). The output of the filter for the in-phase path is heterodyned with a cosine carrier signal. The output of the filter for the quadrature path is heterodyned with a sine carrier signal of the same frequency. The outputs of the in-phase path and the inverted quadrature path shall be summed to form a modulated signal.

The amplitudes of the  $I_n$  and  $Q_n$  components in the transmitted constellations shall maintain the relative values of 1, 3, 5, 7, 9, 11, 13, 15, ... as used in the constellation diagrams derived from Tables I.7 and I.8 with a tolerance of  $\pm 0.06$  relative to these values.

#### I.2.2.3.2.1 Symbol rates and carrier frequencies

All available values of symbol rates ( $SR$ ) for both carriers in both downstream and upstream directions shall be multiples of the Basic Symbol Rate ( $BSR$ ):

$$SR = s \times BSR$$



where  $s$  is an integer,  $BSR = 33.75$  kBaud. The carrier signal frequencies  $f_c$  shall be an integer multiple of  $BSR/2$ :

$$f_c = 0.5 \times BSR \times k \text{ [kHz]}$$

where  $k$  is an integer. The resulting  $f_c$  shifting granularity is equal to 16.875 kHz.

The value of  $SR/f_c$  shall be an exact ratio of two integers under all possible frequency tolerances.

NOTE – The total bit rate ( $TR$ ) provided in a particular direction is determined by symbol rates  $SR_1$ ,  $SR_2$  and constellation sizes  $C_1$ ,  $C_2$  of the first and the second carriers:

$$TR = SR_1 \times \log_2 C_1 + SR_2 \times \log_2 C_2$$

For the given symbol rates, the bit rate can be adjusted with the minimum granularity of  $\min\{SR_1, SR_2\}$ . For the given constellation sizes, the bit rate can be adjusted with the minimum granularity of  $33.75 \times \min\{C_1, C_2\}$  kbit/s.

#### 1.2.2.3.2.2 Spectral shaping filters

The low-pass filters (see Figure I.9) of both carriers shall have the transfer function with a nominal value following the square-root raised-cosine approximation of the frequency response:

$$|G_{nom}(f)| = \begin{cases} 1 & , |f| \leq f_1 \\ \cos\left(\frac{\pi T}{2\alpha} \left[|f| - f_1\right]\right) & , f_1 \leq |f| \leq f_2 \\ 0 & , elsewhere \end{cases}, f_1 = \frac{1-\alpha}{2T}, f_2 = \frac{1+\alpha}{2T}$$

where  $T$  is the symbol period used for the particular carrier, and  $\alpha$  is the excess bandwidth. The excess bandwidth of both low-pass filters shall be identical and in the range of  $\alpha = 0.10$  to  $0.20$ . The default value of the excess bandwidth shall be  $0.2$ . The actual value of the excess bandwidth shall be communicated between the transceivers at both sides of the link over VOC as specified in 1.3.1.2.

The accuracy of implementation of the transfer function  $|G(f)|$  and the group delay distortion  $D$  of the shaping filters shall be as defined in Table I.9. The lower and upper limits of the attenuation are defined as a function of the normalized frequency  $x = \frac{f - f_c}{SR/2}$ .

**Table I.9/G.993.1 – Shaping filter transfer function and group delay distortion templates**

Normalized frequency	$G_{min}$ [dB]	$G_{max}$ [dB]	$D(x) - D_{min}$ [s]
$\leq -1.4$	N/A	$< -40$	N/A
$-1.3$		$< -30$	
$-1.2$		$< -20$	
$-1.15$	$G_{nom} - 4.5$	$G_{nom} + 4.0$	$< 8T$
$-1.1$	$G_{nom} - 3.5$	$G_{nom} + 2.5$	$< 5T$
$-1.05$	$G_{nom} - 3.0$	$G_{nom} + 2.0$	$< 4.5T$



**Table I.9/G.993.1 – Shaping filter transfer function and group delay distortion templates**

Normalized frequency	$G_{\min}$ [dB]	$G_{\max}$ [dB]	$D(x) - D_{\min}$ [s]
-1.0	$G_{\text{nom}} - 1.0$	$G_{\text{nom}} + 1.0$	<4T
-0.95			<3T
-0.9			
-0.8			
0			
0.8			
0.9			
0.95			
1.0			<4T
1.05	$G_{\text{nom}} - 3.0$	$G_{\text{nom}} + 2.0$	<4.5T
1.1	$G_{\text{nom}} - 3.5$	$G_{\text{nom}} + 2.5$	<5T
1.15	$G_{\text{nom}} - 4.5$	$G_{\text{nom}} + 4.0$	<8T
1.2	N/A	<-20	N/A
1.3		<-30	
≥1.4		<-40	

NOTE –  $D_{\min}$  is the minimum group delay within the in-band part of the spectrum:  
 $D_{\min} = \min D(x)$  for  $|x| \leq 1.2$ .

**1.2.3 Receiver functionality**

The receiver demodulates and decodes the incoming signal of both carriers received from the transmission medium, and multiplexes them into an output frame as shown in Figure I.7. At the VTU-R side, receiver functionality also includes recovering the symbol timing.

The demodulation and decoding processes shall be matched with the modulation and encoding processes, respectively, as described in I.2.2.3.

The multiplexing procedure combines the received PMD frames of carrier 1 and carrier 2 into the original transmission frame (see I.1.2), and reconstructs the original frame alignment octets Sync1 and Sync2. The multiplexing procedure shall match the splitting procedure as specified in I.2.2.1.

The receiver shall tolerate delay difference from the transmitter plus the delay difference introduced by the loop.

NOTE – In most of the practical cases the delay difference introduced by the loop is less than 1  $\mu$ s.

**1.2.4 Transmission profile**

The transmission profile is a set of transmission parameters (STP) that define the main characteristics of the VDSL link, such as transport capacity, spectral allocation, and transmit PSD. The STP includes symbol rates, constellations, carrier frequencies and some other parameters of both carriers. The full description of STP is presented in I.4.2.1.

The transceiver shall be capable of providing the following two modes of operation:

- manual mode, when the particular STP for the given loop and type of service is configured by the network operator;

- automatic mode, when the particular STP for the given loop and type of service is automatically selected by the transceiver during the initialization procedure.

In both modes the VTU-O originates the STP to be used and transports it to the VTU-R using VOC as described in I.3.1.2. The VTU-R accepts the STP if the parameter values are from the range specified in I.3.1.2 and sets the profile required by the VTU-O. The particular algorithm of STP selection to be used in automatic mode is left to the discretion of the VTU-O implementers. No specific limitations apply.

### **I.3 Operations and maintenance**

#### **I.3.1 QAM-specific OAM primitives**

##### **I.3.1.1 Line-related OAM primitives**

###### **I.3.1.1.1 Near-end defects**

*Loss-of-Carrier (los\_cr)* defect occurs when the received carrier signal power, averaged over a 0.5-s period, is lower than the set threshold. It terminates when this power, measured in the same way, is at or above the threshold.

*Loss-of-Signal (los)* defect occurs when *los\_cr* defect occurs in any of the carriers specified by the applied transmission profile, and terminates when *los\_cr* is cleared in both carriers.

###### **I.3.1.1.2 Far-end defects**

*Far-end Loss-of-Carrier (flos\_cr)* defect occurs when a *los\_cr* defect is reported in four or more out of six contiguously received far-end indicator reports. The *flos\_cr* is terminated when less than two far-end *los\_cr* indicators are reported out of six contiguously received far-end indicator reports.

*Far-end Loss-of-Signal (flos)* defect occurs when *flos\_cr* defect is reported for any carrier specified by the applied transmission profile, and terminates when *flos\_cr* is cleared in both carriers.

###### **I.3.1.1.3 Near-end and far-end failures**

The default values of TR1, TR2, TS1, TS2, TF1, and TF2 are 0.5 s.

##### **I.3.1.2 ATM path-related OAM primitives**

###### **I.3.1.2.1 Near-end defects**

*Loss of Cell Delineation (lcd)* defect occurs when *ocd* anomaly persists for more than 50 ms; the *lcd* terminates when no *ocd* anomaly is present during at least 50 ms.

###### **I.3.1.2.2 Far-end defects**

*Far-end Loss of Cell Delineation (fled)* defect occurs when *focd* anomaly is present or *fncd* anomaly persists for more than 50 ms, and no *rdi* defect is present. A *fled* defect terminates if neither *focd* nor *fncd* anomaly is present in more than 50 ms.

##### **I.3.1.3 PTM path-related OAM primitives**

###### **I.3.1.3.1 Near-end defects**

*Packet Error (PER)* defect occurs if packet error anomaly persists for more than 0.5 s. The *PER* defect terminates when no *per* anomaly is present in more than 0.5 s.

###### **I.3.1.4 Power-related OAM primitives**

###### **I.3.1.4.1 Near-end and far-end primitives**

The default values of TP1, TP2 are 2.5 s and 5 s, respectively.



#### **I.3.1.4.2 A set of far-end indicators**

The transfer mechanism of the far-end indicators listed in Table 10-5 is specified in I.1.2.2.

### **I.3.2 VDSL overhead channel**

#### **I.3.2.1 VOC functions and description**

A VDSL Overhead Control (VOC) is defined to support the link activation. Additionally, it can provide maintenance and performance monitoring of the link, and modification of the transmission parameters. Communication over VOC is always initiated by the VTU-O; the VTU-R replies to the VTU-O upon successful reception of a message.

##### **I.3.2.1.1 VOC messages**

A VOC message contains an OPCODE octet followed by two DATA octets. The OPCODE value determines the content and type of the message. The following three types of VOC messages are specified:

- COMMAND-type message: The message is sent from the VTU-O to convey information to the VTU-R (WRITE command) or to request information from the VTU-R (READ command).
- ECHO-type message: The message is a reply from the VTU-R to acknowledge receipt of a COMMAND-type message.
- STATUS-type message: This message could be an IDLE message, an EOC message, or an Unable-To-Comply (UTC) message. The IDLE message shall be sent from both the VTU-O and VTU-R when no activity is going over the VOC and *eoc*. The EOC message shall be sent to transfer *eoc* messages. The UTC message shall be sent by the VTU-R as a reply to a COMMAND-type message to indicate the VTU-R's inability to comply with the received command (WRITE or READ).

##### **I.3.2.1.1.1 VOC message transport**

The VOC messages shall be carried through the VDSL link by the 3-octet OC field of the transmission frame (see I.1.2 and I.3.3).

##### **I.3.2.1.1.2 VOC handshake**

A special handshake procedure for COMMAND-type messages shall be used to obtain reliable VOC message transport between the VTU-O and VTU-R. The VOC handshake shall start from at least four IDLE VOC messages and use the following algorithm: At the start of the VOC handshake, both the VTU-O and VTU-R transmit the IDLE message. When a particular command is to be sent, the VTU-O begins and continues transmitting the corresponding COMMAND-type message. The VTU-R shall accept and latch the transmitted COMMAND-type message after it has received identical messages in three transmission frame samples in a row. The VTU-R shall then respond by beginning and continuing to transmit an ECHO-type message corresponding to the accepted COMMAND-type message. If the VTU-R is unable to comply with the received message, it shall transmit a UTC message instead of echoing the COMMAND-type message.

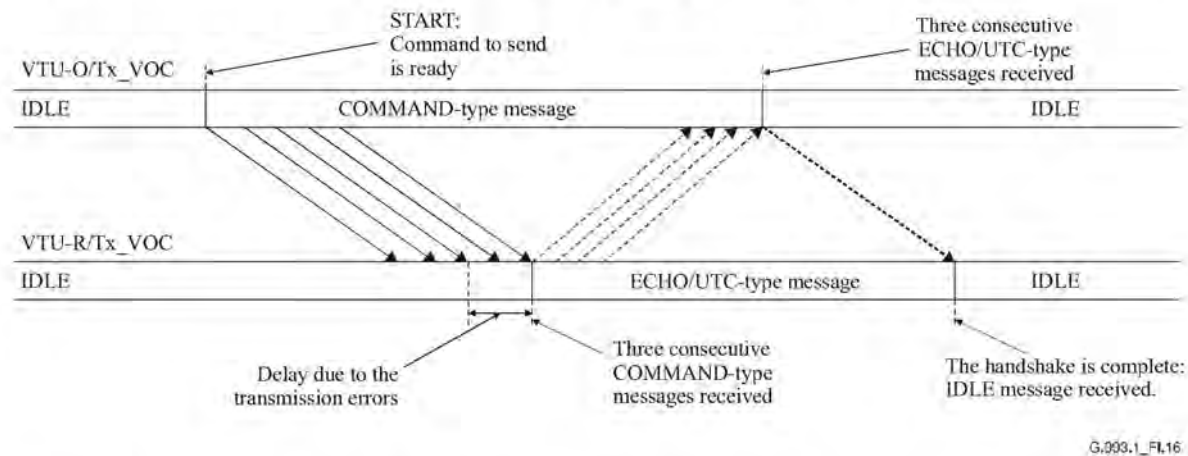
NOTE – At either receiver under-sampling of received frames may occur (i.e., not every received frame need be sampled during the VOC handshake).

After the VTU-O receives correct and identical ECHO-type responses or UTC messages in three frame samples in a row, it shall respond to the VTU-R by beginning and continuing to transmit the IDLE message. When the VTU-R receives an IDLE message, it shall stop transmission of the ECHO or the UTC message, and instead start transmission of IDLE messages at least four times consecutively.

The VTU-O shall continue to send the COMMAND-type message until it detects the correct ECHO or UTC message three samples in a row. Similarly, the VTU-R shall continue to send the echoed message until it receives the IDLE message from the VTU-O. The total VOC handshake time at both the VTU-O and VTU-R shall be limited to 0,9 s.

The VOC handshake process is considered complete when both the VTU-O and VTU-R have resumed transmitting the IDLE message.

An example of the VOC handshake process, under the assumptions that the VTU-R complies with the transmitted VOC command, is illustrated in Figure I.16. The solid arrows indicate the COMMAND-type message sent by the VTU-O, the dashed arrows indicate the VTU-R ECHO, and the dotted arrows indicate IDLE messages sent by both the VTU-O and the VTU-R. Each message is sent during a time corresponding to the number of transmission frames (prior to interleaving – see I.1.2.8) for which the OC field contains the indicated message. Because of interleaving and VOC handshake, there may be a considerable delay in VOC message transitions.



**Figure I.16/G.993.1 – Example of VOC handshake for a successfully communicated command**

#### **I.3.2.1.1.3 VOC handshake flow charts**

The VOC handshake process at the VTU-O shall meet the flow chart presented in Figure I.17; at the VTU-R it shall meet the flow chart presented in Figure I.18.

NOTE 1 – The following notation is used in both Figures I.17 and I.18:

- Rx\_VOC, Tx\_VOC: the received and transmitted VOC message, respectively;
- Echo\_Count: the count of sampled ECHO/UTC messages (at the VTU-O);
- Msg\_Count: the count of sampled COMMAND-type messages (at the VTU-R).

NOTE 2 – The "Correct Echo" in Figure I.17 is an ECHO-type message, which corresponds to the sent COMMAND-type message, or a UTC message.

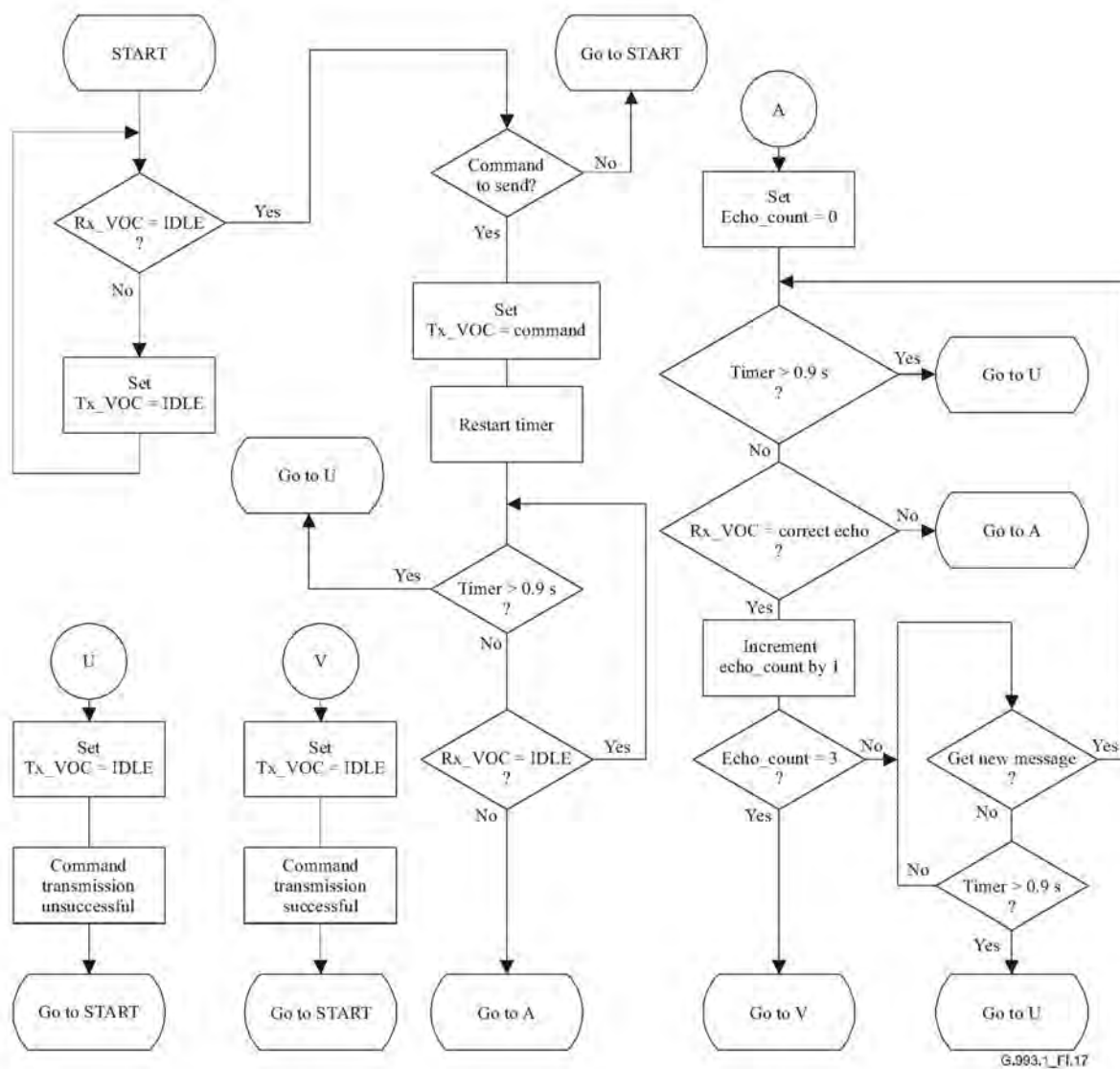


Figure I.17/G.993.1 – VTU-O VOC handshaking flow chart



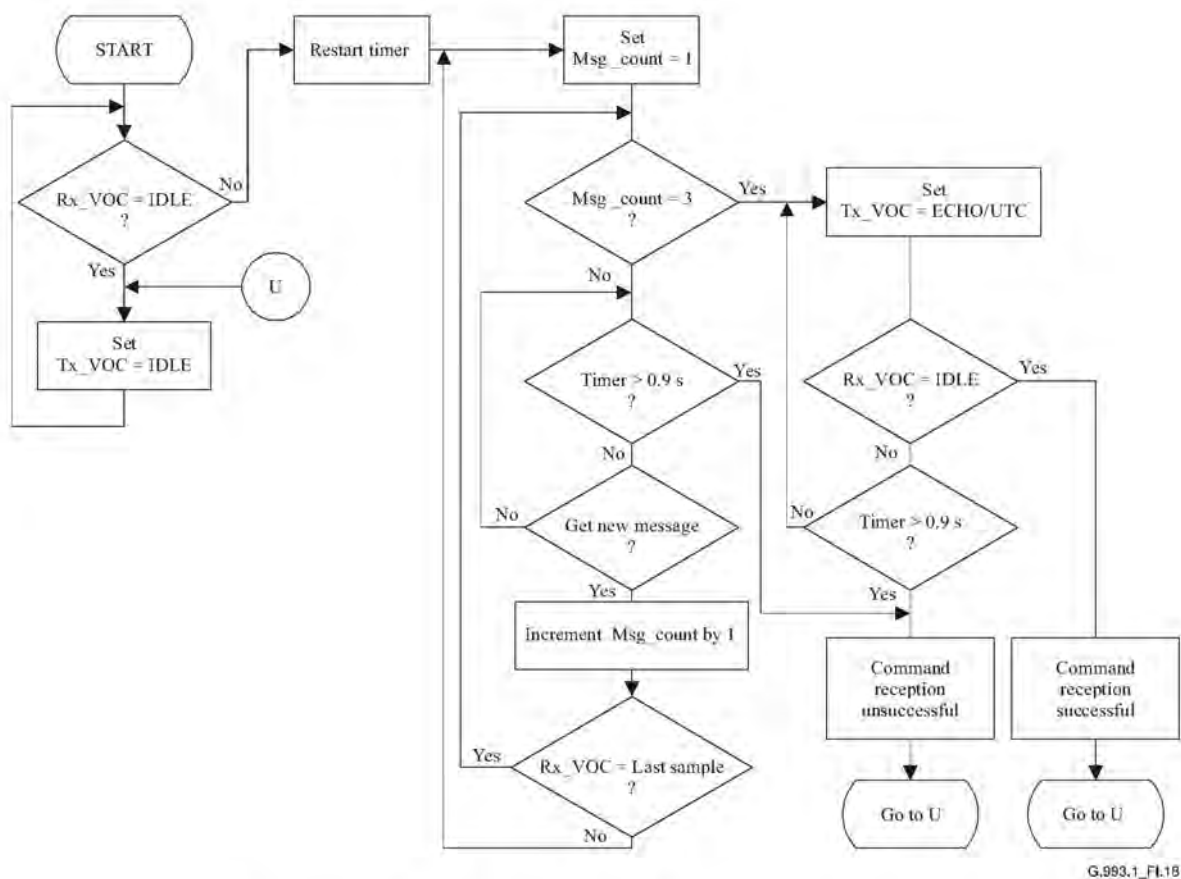


Figure I.18/G.993.1 – VTU-R VOC handshaking flow chart

#### I.3.2.1.1.4 Multiple words communication

A standard VOC message carries two octets of data. In some cases this is not sufficient. The number of data octets carried by VOC messages can be extended by using NEXT\_WORD commands as described below. There are two types of multiple word messages:

- WRITE-type, to send information from the VTU-O to the VTU-R;
- READ-type, to retrieve information from the VTU-R to the VTU-O.

A multiple word message consists of a VOC header, which is a standard VOC message, followed by multiple NEXT\_WORD messages that include the data. The format of READ-type and WRITE-type messages is described in Table I.15.

#### I.3.2.1.1.5 VOC message set

The VOC message set contains five groups of messages:

- STATUS messages;
- Performance monitoring messages;
- Configuration messages;
- Control messages;
- Trigger messages.

The status of the message may be mandatory (M) or optional (O).

Any ECHO-type message shall use the same OPCODE value as the COMMAND-type message it echoes. The DATA field of an ECHO-type message shall contain either the same data as that sent in a COMMAND-type "WRITE" message, or the data requested by a COMMAND-type "READ" message.

#### **1.3.2.1.1.6 Status messages**

The VOC shall support at least the set of STATUS messages presented in Table I.10.

**Table I.10/G.993.1 – STATUS-type VOC messages**

Name	Type	OPCODE	DATA field	Description	Status
IDLE	STATUS	0xFF	0x0000	An IDLE message. Sent by both VTU-O and VTU-R when VOC is inactive	M
EOC	STATUS	0xFC	<i>eoc</i> message	Sent by both VTU-O and VTU-R when OC is used for <i>eoc</i> transport (VOC inactive)	M
UTC	STATUS	0xF0	Same as the COMMAND message being UTC'ed	An Unable-To-Comply message. Sent by the VTU-R when the received command cannot be executed for any reason	M

The UTC message from the VTU-R is a valid response to a COMMAND-type message only if support for the requested command by the VTU-R is optional.

#### **1.3.2.1.1.7 Performance monitoring messages**

Performance monitoring messages are intended to deliver far-end line-related primitives, detected in PMD and PMS-TC sublayers, and other performance parameters obtained by the VTU-R. The OPCODES from 0x90 to 0x9F shall be reserved for proprietary use. The VOC shall support at least the set of Performance monitoring messages presented in Table I.11.

**Table I.11/G.993.1 – Performance monitoring VOC messages**

Name	Type	OPCODE	DATA field	Description	Status
<b>Generic</b>					
VTUR_INFO	COMMAND (READ) and ECHO	0x1F	COMMAND: 0x0000 ECHO: First two octets of the VTU-R INFO data (Note 3)	Requests the VTU-R to send INFO to the VTU-O	M
VTUO_INFO	COMMAND (WRITE) and ECHO	0x1E	COMMAND and ECHO: First two octets of the VTU-O INFO data (Note 3)	Reports the VTU-O INFO to the VTU-R	M

Table I.11/G.993.1 – Performance monitoring VOC messages

Name	Type	OPCODE	DATA field	Description	Status
<b>Line related: PMD</b>					
SNR_REQ	COMMAND (READ) and ECHO	0x01	COMMAND: 2 MSB = DS carrier code, the rest = 0. ECHO: 2 MSB = DS carrier code, 8 LSB = SNR in dB, the rest = 0. LSB weight = 1/4 dB	Requests the VTU-R to send the SNR pertaining to the specified DS carrier in dB	M
SNR_REP	COMMAND (WRITE) and ECHO	0x02	COMMAND and ECHO: 2 MSB = US carrier code, 8 LSB = SNR in dB, the rest = 0. LSB weight = 1/4 dB	Sent by the VTU-O to indicate the SNR pertaining to the specified US carrier in dB	O
ATT_REQ	COMMAND (READ) and ECHO	0x03	COMMAND: 2 MSB = DS carrier code, the rest = 0. ECHO: 2 MSB = DS carrier code; 9 LSB = attenuation in dB, the rest = 0. LSB weight = 1/4 dB	Requests the VTU-R to send attenuation in dB pertaining to the specified DS carrier	M
ATT_REP	COMMAND (WRITE) and ECHO	0x04	COMMAND and ECHO: 2 MSB = US carrier code, 9 LSB = attenuation in dB, the rest = 0. LSB weight = 1/4 dB	Sent by the VTU-O to indicate attenuation in dB pertaining to the specified US carrier in dB	O
Reserved	COMMAND and ECHO	0x05-0x0F			O
<b>Line related: PMS-TC</b>					
FECS_REQ	COMMAND (READ) and ECHO	0x10	COMMAND: 0x0000 ECHO: VTU-R <i>fec-s</i> data as a 16-bit number of errored octets (Note 1)	Requests the VTU-R to send number of errored octets corrected by FEC in the Slow channel since the last FECS_REQ command	M
FECS_REP	COMMAND (WRITE) and ECHO	0x11	COMMAND and ECHO: VTU-O <i>fec-s</i> data as a 16-bit number of errored octets (Note 1)	Reports the number of errored octets corrected by FEC in the VTU-O Slow channel since the last FECS_REP command	O



**Table I.11/G.993.1 – Performance monitoring VOC messages**

<b>Name</b>	<b>Type</b>	<b>OPCODE</b>	<b>DATA field</b>	<b>Description</b>	<b>Status</b>
FECF_REQ	COMMAND (READ) and ECHO	0x12	COMMAND: 0x0000 ECHO: VTU-R <i>fec-f</i> data as a 16-bit number of errored octets (Note 1)	Requests the VTU-R to send the number of errored octets corrected by FEC in the Fast channel since the last FECF_REQ command	O (Note 2)
FECF_REP	COMMAND (WRITE) and ECHO	0x13	COMMAND and ECHO: VTU-O <i>fec-f</i> data as a 16-bit number of errored octets (Note 1)	Reports the number of errored octets corrected by FEC in the VTU-O Fast channel since the last FECF_REP command	O
ERRS_REQ	COMMAND (READ) and ECHO	0x14	COMMAND: 0x0000 ECHO: VTU-R <i>err-s</i> data as a 16-bit number of errored codewords (Note 1)	Requests the VTU-R to send the number of codewords uncorrectable by FEC in the Slow channel since the last ERRS_REQ command	M
ERRS_REP	COMMAND (WRITE) and ECHO	0x15	COMMAND and ECHO: VTU-O <i>err-s</i> data as a 16-bit number of errored codewords (Note 1)	Reports the number of codewords uncorrectable by FEC in the VTU-O Slow channel since the last ERRS_REP command	O
ERRF_REQ	COMMAND (READ) and ECHO	0x16	COMMAND: 0x0000 ECHO: VTU-R <i>err-f</i> data as a 16-bit number of errored codewords (Note 1)	Requests the VTU-R to send the number of codewords uncorrectable by FEC in the Fast channel since the last ERRF_REQ command	O (Note 2)
ERRF_REP	COMMAND (WRITE) and ECHO	0x17	COMMAND and ECHO: VTU-O <i>err-f</i> data as 16-bit number of errored codewords (Note 1)	Reports the number of codewords uncorrectable by FEC in the VTU-O Fast channel since the last ERRF_REP command	O
Reserved	COMMAND and ECHO	0x18–0x1D			O
<b>Proprietary use</b>					
Reserved	COMMAND and ECHO	0x90–0x9F			O

**Table I.11/G.993.1 – Performance monitoring VOC messages**

NOTE 1 – The error count saturates at 65 535.

NOTE 2 – Message shall be mandatory if Fast channel is supported.

NOTE 3 – The VTUR\_INFO and VTUO\_INFO data fields shall consist of the following 12 octets of data, in the order listed:

- Vendor ID (4 octets);
- Revision Number (2 octets);
- Spectral Plan Support and Band Support (2 octets);
- TPS-TC configuration (2 octets);
- BSR support and auxiliary functions (2 octets).

The data fields of VTUR\_INFO/VTUO\_INFO shall be communicated using the NEXT\_WORD commands. The format of the VTUR\_INFO and VTUO\_INFO shall be identical; the format of all octets shall be as specified in Tables I.16 and I.18.

The 2-bit code for identification of the US and DS carrier in Table I.11 shall be as follows:

- 00 – Carrier 1D;
- 01 – Carrier 2D;
- 10 – Carrier 1U;
- 11 – Carrier 2U.

In commands relating to both carriers of the same transmission direction, the LSB shall be set to 0 at the transmit side and omitted at the receive side.

#### **I.3.2.1.1.8 Configuration messages**

Configuration VOC messages are intended to reconfigure the VDSL link by modifying its transmission parameters as described in I.4.2.2. Two types of messages are defined for link configuration: Parameter setting messages and Trigger messages. The Parameter setting messages (Table I.13) deliver the configured parameter value from the VTU-O to the VTU-R Activation database (see I.4.3). The Trigger messages (Table I.14) execute the changing of link transmission parameters to a new setting.

##### **I.3.2.1.1.8.1 Parameter setting messages**

VDSL link configuration is performed by modification of its Set of Transmission Parameters (STP), as described in I.4.2.1, Table I.22. The Parameter setting messages include the targeted upstream or downstream carrier code, the targeted STP code, and the applied parameter value. The VOC shall support at least the Parameter setting messages presented in Table I.13.

All Parameter setting messages are of COMMAND WRITE type; the COMMAND and the ECHO DATA fields shall be equal and contain the parameter value of the particular STP to be set at the VTU-R. The DATA field format of the Parameter setting messages shall be as presented in Table I.12.

**Table I.12/G.993.1 – DATA field format for parameter setting and read-back messages**

D15	D14	D13	D12	D11-D0
STP code		US or DS	Carrier 1 or 2	Parameter value
		Carrier code (Notes 2, 3)		



The following 2-bit combinations shall be used for STP code in Table I.12:

00 – for I\_STP;

01 – for WS\_STP;

10 – for CR\_STP;

11 – setting recommended for CR\_STP (valid for read-back messages only).

The same 2-bit combinations as presented in I.3.2.1.1.7 shall be used in Table I.12 for coding of the DS and US carriers (Carrier code).

In VOC commands relating to both carriers of the same transmission direction (i.e., INTERLV, FRAME) bit D12 shall be set to 0 at the transmit side and omitted at the receive side.

For any Parameter setting message a complementary readback message of COMMAND READ type may be used for verifying the value of the configured parameter. In addition, the readback message may be used for reading the particular parameter value recommended for CR\_STP. A readback message, if used, shall be built in accordance with the following rules:

- The OPCODE of a readback message equals the OPCODE of the corresponding Parameter setting message increased by 0x20 (in the range of OPCODEs from 0x40 to 0x5F);
- The DATA field of a readback message differs from the corresponding Parameter setting message by the parameter value (bits D0-D11) only. The latter is set to zero for the COMMAND, and equals the actual parameter value setting at the VTU-R for the ECHO.

**Table I.13/G.993.1 – Parameter setting messages**

Name	Type	OPCODE	Parameter value	Description	Status
EXCBAND	COMMAND (WRITE) and ECHO	0x29	10 MSB = 0, 2 LSB = extra excess bandwidth above 0.1. The LSB weight = 1/30 (Note 1).	Selects the VTU-R excess bandwidth for both transmission directions	O
INTERLV	COMMAND (WRITE) and ECHO	0x21	2 MSB = $\log_2(S/I)$ for $S/I < 16$ . For $S/I = 16$ , 3 MSB = 1. 8 LSB = M, the rest = 0. M = 0 or 3 MSB = 0 disables the interleaver	Selects the VTU-R interleaving depth for the specified direction and STP	M
FRAME	COMMAND (WRITE) and ECHO	0x22	8 MSB = F, 4 LSB = $RF/2$ (Note 2)	Selects the VTU-R frame format for the specified direction and STP	M
PSDMASK	COMMAND (WRITE) and ECHO	0x23	12-bit PSD mask code (Note 3)	Selects the VTU-R transmit PSD mask for the specified STP	M
PSDLEVEL	COMMAND (WRITE) and ECHO	0x24	4 MSB = 0, 8 LSB = $PSD[dBm/Hz] + 100$ , LSB weight = 1/4 dBm/Hz	Selects the VTU-R transmit PSD level for the specified US carrier and STP	M

Table I.13/G.993.1 – Parameter setting messages

Name	Type	OPCODE	Parameter value	Description	Status
PSDLEVEL_REP	COMMAND (WRITE) and ECHO	0x25	4 MSB = 0, 8 LSB = PSD[dBm/Hz] + 100, LSB weight = 1/4 dBm/Hz	Reports the VTU-O transmit PSD level for the specified DS carrier and STP	O
SMBLRATE	COMMAND (WRITE) and ECHO	0x26	2 MSB = 0, 10 LSB = symbol rate profile $s$ (Note 4)	Selects the VTU-R symbol rate profile for the specified carrier and STP	M
CONSTEL	COMMAND (WRITE) and ECHO	0x27	8 MSB = 0, 4 LSB = $\log_2$ (constellation size)	Selects the VTU-R constellation size for the specified carrier and STP	M
CENFREQN	COMMAND (WRITE) and ECHO	0x28	1 MSB = 0, 11 LSB = centre frequency profile $k$ (Note 5)	Selects the VTU-R centre frequency profile for the specified carrier and STP	M
PSD_REF	COMMAND (WRITE) and ECHO	0x30	<i>First field:</i> 4 MSB = 0, 8 LSB = $a$ [dBm/Hz] + 100, LSB weight = 1/4 dBm/Hz <i>Second field:</i> 3 MSB = 0, 10 LSB = $b$ [dBm/Hz] + 50, LSB weight = 1/20 dBm/Hz	Selects the value of PSD_REF for the specified US carrier (Note 6)	M
PSD_REFS	COMMAND (WRITE)	0x31	4 MSB = 0, 8 LSB = PSD_REFS[dBm/Hz] + 120, LSB weight = 1/4 dBm/Hz	Selects the value of the start-up PSD_REF (I.4.3.5)	M
Reserved	COMMAND and ECHO	0x20, 0x32-0x3F	Note 7		O

**Table I.13/G.993.1 – Parameter setting messages**

NOTE 1 – As an example, the EXBAND value of 0x2 results in the excess bandwidth of $0.1 + 2/30 = 0.167$ (16.7%).
NOTE 2 – The frame format shall be defined by the total number of octets ( $F \leq 180$ ) and the number of redundancy octets ( $RF \leq 16$ ) in the Fast codeword. Valid non-zero values for $F$ and $RF$ shall be as defined in I.1.2.3.
NOTE 3 – The PSD mask code bears the PSD mask specification which is regionally specific. For some regions PSD mask codes could be found in [ETSI] and [ANSI] and in Annex F. The setting for bandwidth of the amateur radio notches shall comply with the specification in 6.2.4.
NOTE 4 – The symbol rate profile is calculated as $s = SR/BSR$ , where $SR$ is the required symbol rate in kBaud, $BSR = 33.75$ kBaud, as defined in I.2.2.3.2.1, unless the VTU_INFO command informs on a different setting.
NOTE 5 – The centre frequency profile is calculated as $K = 0.5 \times f_c / BSR$ , where $f_c$ is the required centre frequency in kHz, $BSR = 33.75$ kBaud (see I.2.2.3.2.1).
NOTE 6 – The command requires two VOC fields and communicated using Next Word commands.
NOTE 7 – The OPCODE 0x20 is reserved for the regionally specific PROFILE message (see [ETSI]).

**I.3.2.1.1.9 Trigger messages**

All Trigger messages are of the COMMAND (WRITE) type. Both the COMMAND field and the ECHO DATA field contents shall be equal to 0xAAAA. The VOC shall support at least the Trigger messages presented in Table I.14.

**Table I.14/G.993.1 – Trigger messages**

Name	Type	OPCODE	Description	Status
CHANGE	COMMAND (WRITE) and ECHO	0xA0	Requests the VTU-R to be ready to change the CR_STP to a new parameter setting upon execution of a trigger procedure (I.4.3.6).	M
IDLREQ	COMMAND (WRITE) and ECHO	0xA1	Requests the VTU-R to be ready to change the CR_STP to I_STP upon execution of a trigger procedure (I.4.3.6).	M
BTSERV	COMMAND (WRITE) and ECHO	0xA2	Requests the VTU-R to be ready to change the CR_STP to WR_STP upon execution of a trigger procedure (I.4.3.6).	M

**I.3.2.1.1.10 Control messages**

Control messages are intended for system maintenance in some special cases and allow the management system to override some routine processes. The VOC shall support at least the Control messages presented in Table I.15.



**Table I.15/G.993.1 – Control messages**

<b>Name</b>	<b>Type</b>	<b>OPCODE</b>	<b>DATA field</b>	<b>Description</b>	<b>Status</b>
USPB_RESET	COMMAND (WRITE) and ECHO	0xE0	COMMAND and ECHO: 2 MSB = US carrier code, the rest = 0	Requests the VTU-R to renew US power back-off process for the specified US carrier	M
THRPUT	COMMAND (WRITE) and ECHO	0xE1	COMMAND and ECHO: 8 MSB = data throughput, 8 LSB = <i>eoc</i> throughput (0x00 = set, 0xFF = reset)	Sets or resets data throughput and <i>eoc</i> throughput at the VTU-R	M
THRPUT_REQ	COMMAND (READ) and ECHO	0xE2	COMMAND: 0x0000 ECHO: 8 MSB = data throughput, 8 LSB = <i>eoc</i> throughput (0x00 = set, 0xFF = reset)	Requests the VTU-R to send the status of data throughput and <i>eoc</i> throughput at the VTU-R	O
NEXT_WORD_W	COMMAND (WRITE) and ECHO	0xE3	COMMAND and ECHO: next two octets of data	Conveys the next two octets of data specified by the last WRITE-type command other than NEXT_WORD_W	M
NEXT_WORD_R	COMMAND (READ) and ECHO	0xE4	COMMAND: 0x0000 ECHO: next two octets of data	Requests the VTU-R to send the next two octets of data specified by the last READ-type command other than NEXT_WORD_R	M
TX_FILTER_REP	COMMAND (WRITE) and ECHO	0xE5	COMMAND and ECHO: 4 MSB = STP code and carrier code (Table I.12), 8 LSB = the first octet of the VTU-O Transmit filter register to be sent to the VTU-R (Note 1), the rest = 0	Reports parameters of the VTU-O transmit filter specified in the Transmit filter register (see I.3.4.3). This command shall precede any change in parameters of the Transmit filter (i.e., sent before the changes take effect).	M

Table I.15/G.993.1 – Control messages

Name	Type	OPCODE	DATA field	Description	Status
TX_FILTER_REQ	COMMAND (READ) and ECHO	0xE6	COMMAND: 4 MSB = STP code and carrier code (Table I.12), the rest = 0. ECHO: 8 MSB = 8 MSB of the COMMAND, 8 LSB = the first octet of the VTU-R Transmit filter register to be sent to the VTU-O (Note 1)	Requests the parameters of the VTU-R transmit filter specified in the Transmit filter register (see I.3.4.3)	M
QUIET	COMMAND (WRITE) and ECHO	0xE7	COMMAND and ECHO: D10 = mode of the non-silenced transceiver, D9 = 1 reports silenced VTU-O, D8 = 1 requests silenced VTU-R, 4 LSB = maximum quiet period in s up to 10, the rest = 0 (Note 2)	Requests the VTU-R to silence its transmitter and reports whether the VTU-O transmitter will be silenced. Either transmitter shall be silenced for up to the specified time period immediately after completion of the VOC handshake. Following the silent period, both modems enter <i>Cold-Start</i> activation. A modem that has not been silenced can request to end the quiet period early by transmitting a QUIET signal followed by DF_STP (Note 3)	M



**Table I.15/G.993.1 – Control messages**

Name	Type	OPCODE	DATA field	Description	Status
COPY_STP	COMMAND (WRITE) and ECHO	0xE8	COMMAND and ECHO: 8 MSB = source STP, 8 LSB = destination STP. STP encoding: 0x00 – CR_STP; 0x01 – DF_STP; 0x02 – WS_STP; 0x03 – WR_STP; 0x04 – RE_STP; 0x05 – I_STP; 0xFF – all STP (except DF_STP)	Requests the VTU-R to copy parameter values of an indicated source STP to an indicated destination STP (DF_STP is allowed only in the source field; see I.4.2.2.1)	M
Reserved	COMMAND and ECHO	0xE9-0xEF			O

NOTE 1 – The TX\_FILTER command communicates parameters of the VTU transmit filter corresponding to the defined STP and the selected carrier. It is assumed that prior to the VOC communication, the filter parameters are loaded into the Transmit filter register using the format specified in I.3.4.3. The filter parameters are sent to or retrieved from the other side by NEXT\_WORD commands. The first octet of the Transmit filter register includes the number of octets to send/retrieve.

NOTE 2 – Bits D9 and D8 of the data field specify that either or both modems shall silence their transmitters for the quiet period specified by bits D3-D0. If both modems are silenced, the quiet period lasts the specified time, after which both modems initiate *Cold-Start* activation (begin transmitting DF\_STP). If only one modem is silenced, the non-silenced modem shall continue to transmit the same signal as before this command if D10 = 0, or may transmit any other signal that complies with PSD mask M1, excluding the QUIET signal (see I.4.3.4), if D10 = 1.

NOTE 3 – The non-silenced modem can request early termination of the quiet period at any time by transmitting the QUIET signal for at least 100 ms followed by DF\_STP, thereby initiating *Cold-Start* activation. The silenced modem may either remain quiet up to the end of the specified time period, or can (but is not required to) terminate the quiet period early if it detects the DF\_STP signal.

Transmission of the NEXT\_WORD\_R/NEXT\_WORD\_W command always refers to the last VOC OPCODE other than NEXT\_WORD\_W/R, IDLE, and EOC that was successfully communicated over the VOC. If the last successfully communicated VOC command was a READ-type, subsequent NEXT\_WORD\_R commands will read the next two octets of data from the VTU-R corresponding to that READ-type command. If the last successfully communicated VOC command was a WRITE-type, subsequent NEXT\_WORD\_W commands will write the next two octets of data into the VTU-R corresponding to that WRITE-type command. NEXT\_WORD\_R or NEXT\_WORD\_W transmissions, which attempt to read or write beyond the data field length defined for the preceding OPCODE, shall be echoed with UTC by the VTU-R. Reception by the VTU-R of a command other than NEXT\_WORD\_R, NEXT\_WORD\_W, or IDLE shall terminate processing of the previous OPCODE. Reception of a single NEXT\_WORD\_R or a single NEXT\_WORD\_W command that does not correspond with the preceding command (either NEXT\_WORD\_R after a WRITE-type command or NEXT\_WORD\_W after a READ-type command) shall be echoed with a UTC.

### I.3.3 Operations Channel TPS-TC (OC-TC) functionality

#### I.3.3.1 Multiplexing of VOC and eoc

The VOC and *eoc* multiplexing/de-multiplexing is based on the OC channel OPCODE value (see I.1.2.1) that distinguishes the OC DATA field contents. The VOC shall get priority in the multiplexing process: if both VOC and *eoc* messages are ready to be sent, the VOC message shall be sent first.

When no VOC message is to be sent in the given Slow codeword, the OC OPCODE octet of this codeword shall be set either to 0xFF or to 0xFC ("IDLE" message OPCODE or "EOC" message opcode, I.3.2.1.1.5). In the case OPCODE=0xFF, 0x0000 shall be inserted into the OC DATA field. In the case OPCODE=0xFC, the next 2 octets of *eoc* message shall be inserted into the OC DATA field. When a non-IDLE VOC message is to be sent, the *eoc* transparency shall be interrupted, and the corresponding VOC OPCODE (see I.3.2.1.1.4) shall be set to transmit a VOC message. When the VOC message transmission is completed, the OPCODE value shall be set to IDLE. After the specified number of IDLE messages is sent (see I.3.2.1.1.1), *eoc* transport over the OC may be resumed.

#### I.3.3.2 De-multiplexing

If the received OC OPCODE equals 0xFC, the contents of the OC DATA field shall be output via the corresponding  $\gamma$ -interface. If the received OC OPCODE is equal to any value other than 0xFF or 0xFC, the received OC DATA field shall be directed to the VOC processor as a possible valid VOC OPCODE (see I.3.2.1.1.5).

NOTE – The value of OC OPCODE 0xFC indicates that the received OC DATA octets may contain an *eoc* message. The *eoc* processor will distinguish a valid *eoc* message as described in 10.3.2.

### I.3.4 VTU-R registers

#### I.3.4.1 VTU-R configuration register

The VTU-R configuration register is intended for storing the VTU-R configuration data, either default or delivered from the VTU-O via VOC. The register consists of 64 bytes and shall include the data as specified in Table I.16:

**Table I.16/G.993.1 – VTU-R configuration register (Register 0x8)**

Byte number, HEX	Parameter description	Format
<b>Line-related</b>		
0x00-0x01	Reserved for use by the ITU-T	For PROFILE code [ETSI] default 0xFF
0x02-0x03	Transmit PSD mask	See Table I.13, PSD_MASK
0x04-0x05	Frame setup	See Table I.13, FRAME
0x06-0x07	Symbol rate, Carrier US1	See Table I.13, SMBOLRATE
0x08-0x09	Symbol rate, Carrier US2	See Table I.13, SMBOLRATE
0x0A-0x0B	Symbol rate, Carrier DS1	See Table I.13, SMBOLRATE
0x0C-0x0D	Symbol rate, Carrier DS2	See Table I.13, SMBOLRATE
0x0E-0x0F	Constellation, Carrier US1	See Table I.13, CONSTEL
0x10-0x11	Constellation, Carrier US2	See Table I.13, CONSTEL
0x12-0x13	Constellation, Carrier DS1	See Table I.13, CONSTEL
0x14-0x15	Constellation, Carrier DS2	See Table I.13, CONSTEL
0x16-0x17	Centre frequency, Carrier US1	See Table I.13, CENFREQN



**Table I.16/G.993.1 – VTU-R configuration register (Register 0x8)**

Byte number, HEX	Parameter description	Format
0x18-0x19	Centre frequency, Carrier US2	See Table I.13, CENFREQN
0x1A-0x1B	Centre frequency, Carrier DS1	See Table I.13, CENFREQN
0x1C-0x1D	Centre frequency, Carrier DS2	See Table I.13, CENFREQN
0x1E-0x1F	Excess bandwidth, US Carriers	See Table I.13, EXCBAND
0x30-0x31	Excess bandwidth, DS Carriers	See Table I.13, EXCBAND
0x32-0x33	PSD_REF, Carrier US1, value a	See Table I.13, PSD_REF
0x34-0x35	PSD_REF, Carrier US1, value b	See Table I.13, PSD_REF
0x36-0x37	PSD_REF, Carrier US2, value a	See Table I.13, PSD_REF
0x38-0x39	PSD_REF, Carrier US2, value b	See Table I.13, PSD_REF
0x3A-0x3B	Startup PSD_REF	See Table I.13, PSD_REFS
0x3C-0x3F	Reserved	0xFF
0x40-0x41	Interleaver set-up	See Table I.13, INTERLV
0x42-0x43	Spectral plan support and band support	See Note 1
0x44-0x45	Transmit PSD level, carrier US1	See Table I.13, PSDLEVEL
0x46-0x47	Transmit PSD level, carrier US2	See Table I.13, PSDLEVEL
0x48-0x49	Transmit PSD level, carrier DS1	See Table I.13, PSDLEVEL
0x4A-0x4B	Transmit PSD level, carrier DS2	See Table I.13, PSDLEVEL
0x4C-0x4D	BSR support and auxiliary functions	See Note 2
0x4E-0x4F	Reserved	
<b>Path-related</b>		
0x20-0x21	TPS-TC configuration	See Note 3, Note 4
0x22-0x23	ATM-TC configuration	Reserved, default 0xFF
0x24-0x25	STM-TC configuration	Reserved, default 0xFF
0x26-0x27	PTM-TC configuration	Reserved, default 0xFF
0x28-0x2F	Reserved	0xFF
<p>NOTE 1 – The spectral plan code format shall be as defined in Table I.17, and the band support code format shall be as defined in Table I.18. In Table I.17 a value of 1 indicates support for the spectral plan as specified in 6.1, including regionally-specific band plans (Annexes A-C) and ETSI applications defined in [ETSI]. Value of 0 indicates no support. In Table I.18 a value of 1 indicates support of the particular band, and a value of 0 indicates no support.</p> <p>NOTE 2 – The format of byte 0x4C shall be: D0-D3 set to 0; D4-D5 BSR support; D6, D7 reserved. The following coding shall be used for D4D5:</p> <p>00 Supports BSR = 67.5 kBaud only (legacy value)</p> <p>01 Supports BSR = 33.75 kBaud only (nominal value)</p> <p>10, 11 Reserved.</p> <p>Byte 0x4D is reserved for auxiliary functions. All reserved bits shall be set to 1.</p>		

**Table I.16/G.993.1 – VTU-R configuration register (Register 0x8)**

NOTE 3 – Use the following bits of 0x20: D0, D1 for ATM-TC; D3, D4 for STM-TC; D5, D6 for PTM-TC. Use the following coding:	
00	Not installed
11	Installed and activated
10	Installed and disabled
01	N/A
NOTE 4 – The format of byte 0x21 shall be: D0-D3 TPS-TC defect indicators $fp_1 - fp_4$ , respectively, the rest of the bits is reserved and shall be set to 1. The definition and coding of $fp$ shall be as specified in I.1.2.2.2.	

**Table I.17/G.993.1 – Spectral plan support code (byte 0x42)**

D7	D6	D5	D4	D3	D2	D1	D0
0	0	0	Annex C	ETSI FTTCab B	ETSI FTTCab A	Annex B	Annex A

**Table I.18/G.993.1 – Band support code (byte 0x43)**

D7	D6	D5	D4	D3	D2	D1	D0
0	0	US2	DS2	US1	DS1	25-138, DS	25-138, US

**I.3.4.2 VTU-R performance registers**

Performance registers are intended to store the VTU-R performance-related and loop-related information. The registers shall include data as specified in Table I.19:

**Table I.19/G.993.1 – VTU-R performance registers**

Byte number, HEX	Parameter description	Format
<b>Register 0x3: Self-test results</b>		
0x00-0x0F	Reserved	0xFF
<b>Register 0x4: Performance</b>		
0x00-0x01	Corrected error octets, Slow channel	See Table I.11, FECS
0x02-0x03	Corrected error octets, Fast channel	See Table I.11, FECF
0x04-0x05	Uncorrected error octets, Slow channel	See Table I.11, ERRS
0x06-0x07	Uncorrected error octets, Fast channel	See Table I.11, ERRF
0x08-0x0A	Reserved	0xFF
<b>Register 0x6: Loop attenuation</b>		
0x00	Carrier DS1	See I.3.1, (Note 1)
0x01	Carrier DS2	
0x02	Carrier US1	
0x03	Carrier US2	



**Table I.19/G.993.1 – VTU-R performance registers**

Byte number, HEX	Parameter description	Format
0x04	Electrical length, US	Note 2
0x05	Electrical length, DS	
0x06-0x0F	Reserved	
Register 0x7: SNR margin		
0x00	SNR-M, Carrier DS1	See 10.5
0x01	SNR-M, Carrier DS2	
NOTE 1 – The value of attenuation for carriers US1 and US2 shall be set to 0x00 if no relevant data from the VTU-O is available.		
NOTE 2 – The values of electrical length should be calculated using carrier attenuation data and set to 0x00 if no relevant data is available.		

**I.3.4.3 VTU transmit filter register**

The Transmit filter register at both the VTU-O and VTU-R shall include the data as specified in Table I.20. The data relates only to the part of the filter operating at symbol rate.

**Table I.20/G.993.1 – Transmit filter register**

Byte number, HEX	Parameter description	Format
0x00	Length of the register, L octets	0x01-0xFF, Note 1
0x01	Number of zeros, NZ (NZ × 4 octets)	Notes 2, 3
0x02-0x03	First zero, real part	
0x04-0x05	First zero, imaginary part	
0x06-0x07	Second zero, real part	
0x08-0x09	Second zero, imaginary part	
...		
0x(4 × NZ – 2)-0x(4 × NZ – 1)	NZ-zero, real part	
0x(4 × NZ)-0x(4 × NZ + 1)	NZ-zero, imaginary part	
0x(4 × NZ + 2)-0x(4 × NZ + 3)	First pole, real part	
0x(4 × NZ + 4)-0x(4 × NZ + 5)	First pole, imaginary part	
...		
0x(4 × (NZ + NP) – 2)-0x(4 × (NZ + NP) – 1)	NP-pole, real part	
0x(4 × (NZ + NP))-0x(4 × (NZ + NP) + 1)	NP-pole, imaginary part	
NOTE 1 – The length of the register L equals the total number of octets specifying NZ zeros and NP poles of the transmit filter: L = 4 × (NZ + NP).		
NOTE 2 – Both poles and zeros shall be listed in ascending order.		
NOTE 3 – The real and imaginary parts of the poles and zeros shall be represented by 16 bits each, 2's complement representation, where 2 <sup>14</sup> corresponds to 1.		

If parameters of the transmit filter are not available, the value of L shall be set to 0.



## 1.4 Link activation and de-activation

The link activation/deactivation process is intended to establish/terminate a VDSL link with required transmission parameters between physically connected and powered VTU-O and VTU-R. The process also allows modification of the transmission parameters of the VDSL link. The VTU activation procedure commences with the handshake procedures described in ITU-T Rec. G.994.1. The Annex I NPar(2) and SPar(2) G.994.1 Handshake bit definitions are specified in I.4.4. If G.994.1 procedures select this annex as the mode of operation, the VTU shall transition to Annex I/G.993.1 operation at the conclusion of G.994.1 operation.

### 1.4.1 VDSL link state and timing diagram

The VDSL link state and timing diagram is described in Figure I.19. The diagram includes five states (rounded blocks), four procedures of link activation (rectangular blocks), and two procedures of link deactivation.

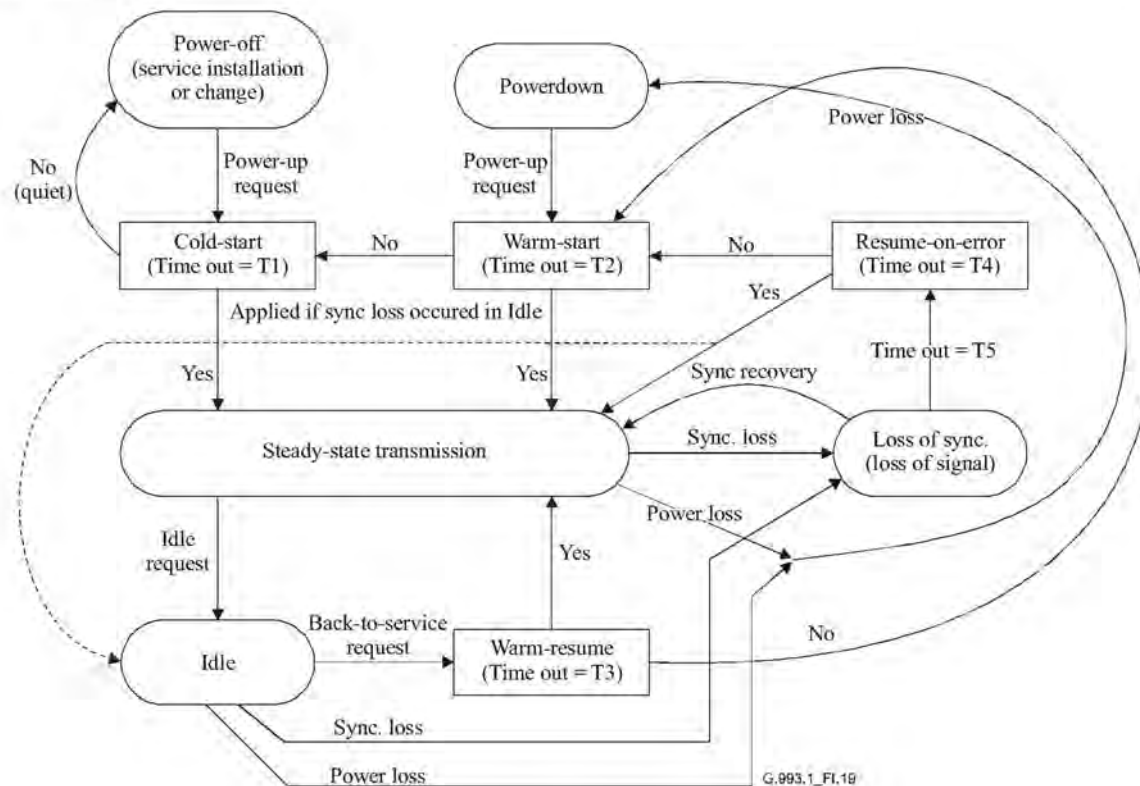


Figure I.19/G.993.1 – VDSL link state and timing diagram

#### 1.4.1.1 States

The link State and Timing diagram shall contain the following five states:

- *Power-off* is the initial state intended for service installation and modification prior to the first power-up process.
- *Steady-State Transmission* is a state achieved after the link activation process is completed. In this state, the link shall transport user information with standard performance characteristics.
- *Loss of Sync (Loss of Signal)* is a state achieved if transmission frame synchronization loss occurs (also as a result of signal energy loss or symbol timing loss). During this state the link is interrupted. The link shall return from this state back to *Steady-State Transmission* if

frame synchronization is recovered in a short period of time (T5). Otherwise, the link shall be moved to perform the *Resume-on-Error* activation procedure.

- *Power-Down* is a state achieved after a guided power removal, power failure or *QUIET* deactivation at either the VTU-O or VTU-R. During this state the link is terminated. The link shall be moved from this state into the *Warm-Start* procedure by applying a Power-up request.
- *Idle* state generates low crosstalk and reduced power consumption for the link when no broadband calls are in progress. After the VTU-O or VTU-R detects a broadband call wake-up signal (Back-to-Service request command) from the network or from the CPE, respectively, a *Warm-Resume* procedure is executed. Support of *Idle* state is optional.

If the VDSL link is maintained during the *Idle* state, at least data frame synchronization, VOC transparency and Sync. Loss event monitoring should be provided. The user data and eoc transport are optional.

#### **1.4.1.2 Activation**

Either the VTU-R or the VTU-O is capable to activate the link. A successfully completed activation brings the link into steady-state transmission. The following four types of link activation (Figure I.19) correspond to the four activation procedures:

- *Cold-Start*: shall be applied after the first power-up or after an unsuccessful *Warm-Start* activation. If finished unsuccessfully, some changes in the installed service shall be made to simplify the link establishment.

NOTE 1 – Unsuccessful *Cold-Start* activation usually occurs when the activated link environment (loop attenuation, noise, etc.) is too poor to provide the desired service.

- *Warm-Start*: shall be applied after an unsuccessful *Resume-on-Error* activation, or after an unsuccessful *Warm-Resume* activation, or after either Power-down/Power failure, or after link deactivation (*QUIET*) event. If *Warm-Start* fails, the *Cold-Start* activation is applied.

NOTE 2 – Unsuccessful *Warm-Start* activation usually occurs after significant change of line characteristic (for example, a connection to a new line with unknown parameters).

- *Resume-on-Error* shall be applied after a link interruption due to loss of synchronization, which was not self-recovered during the specified time-out (T5). If *Resume-on-Error* fails, the *Warm-Start* activation is applied.

NOTE 3 – Unsuccessful *Resume-on-Error* activation is usually due to a temporary change of noise conditions in the loop or due to modification of the transmission parameters.

- *Warm-Resume* shall be applied on receipt of a broadband call wake-up signal (Back-to-Service request command) if the link resides in the *Idle* state. If *Warm-Resume* fails, the *Warm-Start* activation is applied.

NOTE 4 – Unsuccessful *Warm-Resume* activation is usually due to a temporary change of noise conditions in the loop.

#### **1.4.1.3 Deactivation**

The deactivation process may be initiated at either the VTU-O or VTU-R by special control signals. Both the VTU-O and VTU-R should support two types of link deactivation.

- *QUIET* shall terminate the link. *QUIET* shall be applied if power failure occurs, or if a transceiver restart is desired, or as a part of the power-down process. *QUIET* may be initiated while the link resides in any state or during any activation process. In any case, except the *Cold-Start*, after *QUIET* deactivation the link shall be moved into the *Power-Down* state. *QUIET* deactivation during the *Cold-Start* moves the link into the initial (Power-off) state.



- *Idle Request* shall move the link from the Steady-state transmission into the Idle state (if supported). The *Idle Request* command (see I.4.3.2) may be applied on receipt of a broadband call release while the link resides in *Steady-State Transmission* state only.

NOTE – The *Warm-Resume* activation procedure is applied to return the link from the *Idle* state to a *Steady-State Transmission* state.

#### 1.4.1.4 Delay to service

Delay to service is defined by the activation time, which is the time interval from the beginning of the activation process until the link reaches the steady-state transmission. The activation time shall not exceed the values of the time constants T1-T5, listed in Table I.21.

**Table I.21/G.993.1 – Activation time constants**

Process	Time constant	Maximum value [ms]
Cold-Start activation	T1	10 000
Warm-Start activation	T2	5 000
Warm-Resume activation	T3	100
Resume-on-Error activation	T4	300
Sync. Loss recovery	T5	200

#### 1.4.2 VDSL link transmission parameters

##### 1.4.2.1 Set of transmission parameters

Transmission characteristics of the link are specified by the Set of Transmission Parameters (STP) presented in Table I.22. The same STP shall be set at both the VTU-O and VTU-R. When STP is modified in one VTU, the change should occur in the other as well.

**Table I.22/G.993.1 – Set of transmission parameters (STP)**

Parameter	Downstream carrier-1	Downstream carrier-2	Upstream carrier-1	Upstream carrier-2	Parameter range
Symbol rate	1D_SR	2D_SR	1U_SR	2U_SR	$33.75 \text{ kBaud} \times s$ ( $s = 1, 2, \dots$ )
Excess bandwidth	1D_EB	2D_EB	1U_EB	2U_EB	$\alpha = 0.1\text{-}0.2$
Constellation	1D_C	2D_C	1U_C	2U_C	1-12 bit/symbol
Centre frequency	1D_CF	2D_CF	1U_CF	2U_CF	$16.875 \text{ kHz} \times k$ ( $k = 1, 2, \dots$ )
Transmit PSD	1D_PSD	2D_PSD	1U_PSD	2U_PSD	As specified in 6.2.1
Interleaver	D_M, D_I		U_M, U_I		$M, I$ , as specified in I.1.2.8
Frame format	D_FR		U_FR		In accordance with I.1.2.1

##### 1.4.2.1.1 Current STP

The *Current STP* (CR\_STP) contains transmission parameters currently in use by the upstream and downstream transmitters.

#### 1.4.2.1.2 Standard STPs

The following five standard STPs shall be supported.

*Default STP* (DF\_STP) shall be used to perform *Cold-Start* activation. DF\_STP shall be available at both sides of the link prior to the post-handshake activation/deactivation process, and shall be kept constant until the link is returned to *Power-off* state or G.994.1 handshake state to change the type of service. The parameter values for DF\_STP depend on the used bandplan. For band plans specified in Annexes A, B and C, the recommended DF\_STP values are presented in Table I.23. The relevant values of DF\_STP setting are delivered to the VTU-R using ITU-T Rec. G.994.1.

**Table I.23/G.993.1 – Parameter values of DF\_STP applicable for Annexes A, B and C**

Parameter	1D	2D	1U	2U (Note 1)
Symbol rate [kBaud]	573.75 (17 × 33.75)	0	Annexes A, B: 742.5 (22 × 33.75)  Annex C 945 (28 × 33.75)	67.5 (2 × 33.75)
Excess bandwidth	0.2			
Constellation	4	–	4	4
Centre frequency [kHz]	1451.25 (86 × 16.675)	–	Annexes A, B 4455 (264 × 16.875)  Annex C 3138.75 (186 × 16.875)	84.375 (5 × 16.875)
Transmit PSD [dBm/Hz]	–60	–	≤ –60 (Note 2)	–40
Interleaver	Disabled			
Frame format	Type [0/0] (single latency)			
NOTE 1 – The 2U component is an alternative to 1U component, intended to be used when the optional band is in use. The 2U component shall be disabled if ISDN service splitter is involved.				
NOTE 2 – The actual transmit PSD value will be reduced in accordance with the upstream power back-off procedure defined in I.4.3.5.				
NOTE 3 – Specific regions may use other values of DF_STP parameters, compatible with local regulations and interoperability (backwards compatibility) issues.				

*Warm-Start STP* (WS\_STP) shall be used to perform *Warm-Start* activation. WS\_STP shall initially be set equal to the DF\_STP. A VOC communication may be used to negotiate changes to WS\_STP.

*Warm-Resume STP* (WR\_STP) shall be used to perform *Warm-Resume* activation. As the link enters *Steady-State Transmission* state, WR\_STP shall be set equal to CR\_STP. This setting shall be completed prior to execution of *Idle Request*.

*Resume-on-Error STP* (RE\_STP) shall be used to perform a *Resume-on-Error* activation. As the link enters either *Steady-State Transmission* state or *Idle* state, and during these states, RE\_STP shall be set equal to CR\_STP. This setting shall be completed prior to a *Resume-on-Error* activation.

*Idle STP* (I\_STP) shall be used to execute an *Idle Request* (transition to *Idle* state, if supported). By default I\_STP shall be set equal to CR\_STP, except for constellation size, which shall be set to 4, and the transmit PSD level, which shall be reduced by the values presented in Table I.24. Alternative settings for I\_STP shall be completed prior to execution of *Idle Request* using the VOC communication to negotiate the I\_STP setting.



**Table I.24/G.993.1 – Maximum PSD reduction**

Steady-state transmission constellation	4	8	16	32	64 and more
Maximum PSD reduction, dB	3	7	10	12	12

**I.4.2.2 Transmission parameters modification**

At the discretion of the network operator, both CR\_STP and any standard STPs, excepting DF\_STP, can be modified, as appropriate for the required service characteristics. Modification of STP can be initiated only by the VTU-O. The VTU-R is not required to accept the requested STP modification if the value of its transmission parameters is not a standard setting.

NOTE – DF\_STP may be changed upon the service re-installation by procedures that are described in I.4.2.1.2.

**I.4.2.2.1 Standard STP modification**

Of the five standard STPs described in I.4.2.1.2, only WS\_STP and I\_STP may be modified independently. Modification of WS\_STP or I\_STP may be done only during the *Steady-State Transmission* state of the link. The modification technique shall be as follows. The VTU-O gets the new settings for the intended STP from the local management system. It sends to the VTU-R (using the VOC) a copy of the new STP, and requests to make corresponding changes to its own copy of the corresponding STP. Once accepted by the VTU-R, the new STP settings are stored in both the VTU-O and VTU-R.

The RE\_STP shall be automatically updated to equal the CR\_STP each time the link enters *Steady-State Transmission* state or *Idle* state. Similarly, WR\_STP shall be automatically updated to equal the CR\_STP each time the link enters *Steady-State Transmission* state.

**I.4.2.2.2 CR\_STP modification**

The CR\_STP may be modified in two different ways.

- The CR\_STP shall be automatically overwritten with DF\_STP, WS\_STP or RE\_STP when the link enters *Cold-Start*, *Warm-Start*, or *Resume-on-Error*, respectively. During these changes the link is usually interrupted (or disconnected).
- The CR-STP shall be overwritten with a new setting after successful communication of a VOC trigger message (either CHANGE or BTSERVC or IDLEREQ), followed by a trigger handshake (see I.4.3.5). The procedure shall be used both to make generic modifications to CR\_STP, and to modify CR\_STP to I\_STP or to WR\_STP upon transition into *Idle* state or entering *Warm-Resume*, respectively. The CR\_STP modification shall be initiated by a special control signal from the VTU-O (CHNG\_PRM, B\_SERV or I\_REQ, see I.4.3.2). It can be performed either during *Steady-State Transmission* state (if initiated by CHNG\_PRM or I\_REQ), or during *Idle* state (if initiated by B\_SERV).

Modifications of CR\_STP are accompanied by appropriate changes in both transmitter and receiver parameters, and in transmit signal parameters, as defined by the new CR\_STP.

For a generic CR\_STP modification, the CR\_STP modification request and the new CR\_STP shall be conveyed to the VTU-R from the VTU-O over the VOC. After all parameters of the new CR\_STP are successfully communicated, the VTU-O management system uses a CHANGE VOC message to request that the current CR\_STP be overwritten with the new parameter settings. A trigger handshake activated after successful communication of the CHANGE message overwrites CR\_STP and RE\_STP at both the VTU-O and the VTU-R with the new parameter settings, and triggers the desired change in their transmitter/receiver parameters.

In the same manner, for transition into *Idle* state or for *Warm-Resume* activation, the CR\_STP and RE\_STP are overwritten with I\_STP or WR\_STP, respectively, after successful communication of IDLEREQ or BTSERVC VOC messages followed by a trigger handshake.



If due to the CR\_STP change the link moves into *Loss of Sync* state (caused by symbol rate change, for example), it will try to recover synchronization within time T5 and thereby return to *Steady-State Transmission* state with the new parameters in place. If the synchronization is not recovered, the link will attempt a *Resume-on-Error* activation with RE\_STP set equal to the modified CR\_STP. If this *Resume-on-Error* activation is successful, the link returns to *Steady-State Transmission* with the successfully accomplished parameter change. If not, the parameter change process fails, and *Warm-Start* activation is automatically attempted to return the link into the *Steady-State Transmission* state.

NOTE – With some additional delay, a generic CR\_STP modification can also be done without use of the CHANGE VOC command and the trigger handshake. The method is to load new transmission parameters into WS\_STP, and then to force a *Warm-Start* by deactivating the link applying the *QUIET* control signal at either end of the link. Failure to acquire the link with the new parameter values automatically initiates *Cold-Start*, which returns the link into *Steady-State Transmission* state with DF\_STP, ready for the next parameter modification attempt.

#### I.4.2.2.3 STP modification summary

A summary of the STP modification rules is presented in Table I.25.

**Table I.25/G.993.1 – Summary of STP modification rules**

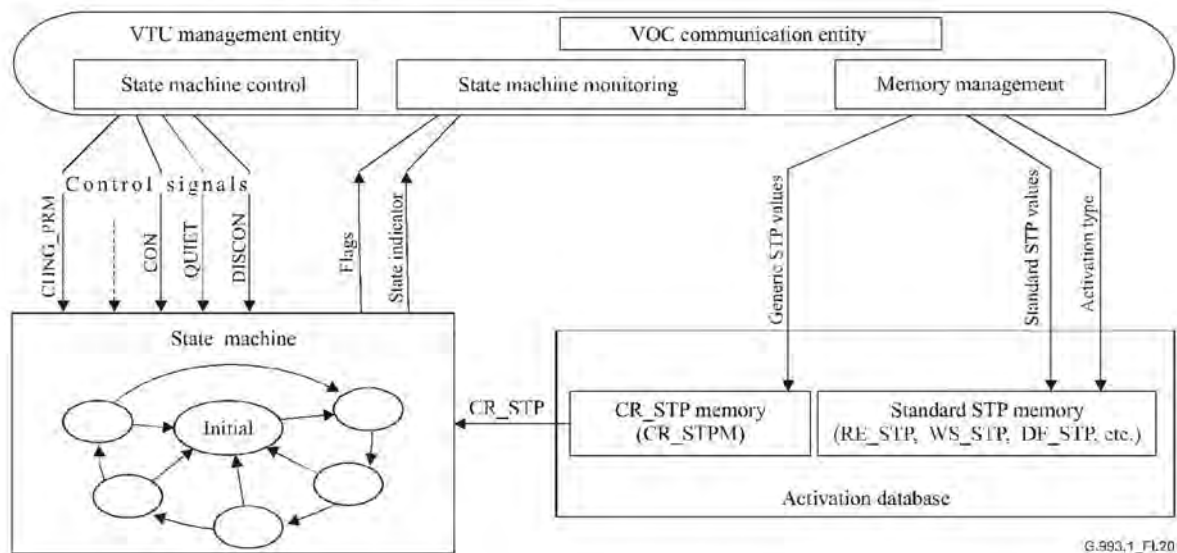
Parameter	Overwritten automatically	Overwritten by the operator
DF_STP	N/A	N/A
WS_STP I_STP	N/A	– with an arbitrary parameter setting during <i>Steady-State Transmission</i> state.
WR_STP	– with the CR_STP upon entry to <i>Steady-State Transmission</i> state.	N/A
RE_STP	– with the CR_STP upon entry to either <i>Steady-State Transmission</i> or <i>Idle</i> state; – with the CR_STP, immediately after CR_STP was overwritten with the new parameter settings (I_STP, WR_STP or generic).	N/A
CR_STP	– with the DF_STP, WS_STP, or RE_STP at the beginning of <i>Cold-Start</i> , <i>Warm-Start</i> , or <i>Resume-on-Error</i> activation, respectively.	– with an arbitrary transmission parameter setting during <i>Steady-State Transmission</i> , after successful communication of the CHANGE VOC message followed by a trigger handshake (generic CR_STP modification); – with I_STP upon entering <i>Idle</i> state after successful communication of the IDLEREQ VOC message followed by a trigger handshake (moving into <i>Idle</i> state); – with WR_STP upon entry to <i>Warm-Resume</i> , after successful communication of the BTSERV VOC message followed by a trigger handshake (moving back from <i>Idle</i> state to <i>Steady-State Transmission</i> ).

NOTE – All listed STP modifications are fully provided by the VTU-O and VTU-R state machines described in I.4.3.6 and I.4.3.7.

### 1.4.3 Post-G.994.1 Handshake VTU activation/deactivation

#### 1.4.3.1 Functional diagram

The VTU post-G.994.1 handshake activation/deactivation functional diagram is shown in Figure I.20. The post-G.994.1 handshake activation/deactivation process is performed by the VTU state machine, described in I.4.3.6 and I.4.3.7. Prior to post-G.994.1 handshake activation, the VTU state machine shall be supplied with the appropriate CR\_STP to be used in the activation. (In Figure I.20, CR\_STP is stored in CR\_STP Memory (CR\_STPM) of the VTU Activation database.) The CR\_STP is loaded by the VTU management entity for the subsequent activation type, and could be either an appropriate standard STP (DF\_STP, WS\_STP, or RE\_STP) or a generic STP. Thus, the VTU management entity supports the desired link characteristics and all the required activation types, as defined in Figure I.19. The post-G.994.1 handshake activation/deactivation is driven by the Control signals originated by the VTU management entity, which shall also monitor the state machine states and flags.



**Figure I.20/G.993.1 – VTU activation/deactivation functional diagram**

The CR\_STPM shall contain the STP for the pending activation process. Identical STP shall be loaded into the CR\_STPM at both the VTU-O and VTU-R at the start of the activation and kept constant until the activation process is completed, either successfully or not. If the activation process is completed successfully, the loaded CR\_STP will be used during the following steady-state transmission until a new parameter modification request. If the activation process fails, a new STP will be automatically loaded into CR\_STPM in accordance with the next activation type, as described in Figure I.19.

#### 1.4.3.2 Control signals

The following Control signals shall be supported to drive the VTU post-G.994.1 handshake activation/deactivation process:

- *Connect (CON)* – to initiate the activation process after the link was terminated (i.e., initiates either *Cold-Start* or *Warm-Start*). As *CON* is set, the VTU shall move from the *STANDBY* state (see I.4.3.6 and I.4.3.7) to start the link activation. *CON* is applied at the VTU-R in case of activation from the CPE site, and at the VTU-O in the case of activation from the ONU/CO site, *CON* shall be ignored by the VTU in all states except *STANDBY*.



- *Quiet (QUIET)* – to terminate the link. As *QUIET* is set, the activated VTU shall move from its current state into the POWER-UP state (see I.4.3.6 and I.4.3.7). *QUIET* should be applied for the VTU restart or as a part of the power-down process. *QUIET* is applicable for both the VTU-O and VTU-R.
- *Change parameter (CHNG\_PRM)* – to initiate a generic parameter modification process. *CHNG\_PRM* may be applied only at the VTU-O while the link is in *Steady-State Transmission* state.
- *Idle Request (I\_REQ)* – to initiate the link deactivation into *Idle* state. As *I\_REQ* is set, the link shall move from *Steady-State Transmission* into *Idle* state. *I\_REQ* may be applied at the VTU-O only while the link is in *Steady-State Transmission* state. *I\_REQ* shall be supported only if *Idle* state is supported.
- *Back-to-Service (B\_SERV)* – to initialize a *Warm-Resume* activation. As *B\_SERV* is set the link shall move from *Idle* state into *Steady-State Transmission* state. *B\_SERV* may be applied at both the VTU-O and VTU-R while the link is in *Idle* state. *B\_SERV* shall be supported only if *Idle* state is supported.
- *Disconnect (DISCON)* – to disable the link activation attempt from the VTU-R (to prevent uncontrolled link activation). *DISCON* may be applied at the VTU-O only. Support of the *DISCON* is optional.

#### **1.4.3.3 Flags and indicators**

The local VTU management entity shall use the following Flags and Indicators to monitor the state machine.

- *State Indicator (SI)* – to indicate the current state of the state machine. Used by the VTU management entity to set or reset user data and *eoc* throughput.
- *Complied Flag (CF)* – to indicate that the last command initiated by a particular Control signal was successfully executed.
- *Unable-to-Comply Flag (UTCF)* – to indicate that the last command initiated by a particular Control signal was not executed.
- *Remote Activation Request Flag (RAF)* – to indicate that an activation request from the VTU-R has been received; applicable at the VTU-O while in *STANDBY* state only.
- *Back to Service Request Flag (BTSF)* – indicates that a back-to-service request from the VTU-R has been received; applicable at the VTU-O while the link is in *Idle* state only. Shall be supported only if *Idle* state is supported.

#### **1.4.3.4 Transmit signals and timers**

A particular type of transmit signal is specified for each state of the VTU state machine. The VTU shall support all types of transmit signal specified in Table I.26.

Transmit signals O\_QUIET and R\_QUIET shall drive the line with zero volts (silence). Other transmit signals shall be formatted as a standard transmission frame (see I.1.2) and specified by the contents of the OC field, and the *o\_trig*, *r\_trig*, *r\_flag* signals (see I.1.2.2.2), and the values of indicators IB-7 through IB-9. Transmit signals O\_ACQUIRE and R\_ACQUIRE, O/R\_TRIG always carry, respectively, the PSD\_REFS VOC message and IDLE VOC message; signals O/R\_DATA can carry both IDLE messages, and valid VOC and *eoc* messages.

The *o\_trig* bits in the downstream transmission frame header shall be set to 1 for the O\_TRIG signal and to 0 for all other VTU-O transmit signals. The *r\_trig* bit shall be equal to 0 for all VTU-R transmit signals, except for R\_TRIG, where it is set to 1. The *r\_flag* shall be set to 0 in all signals except R\_DATA, in which it shall be set to 1 when the B\_SERV control signal is applied at the VTU-R.

**Table I.26/G.993.1 – Transmit signals summary**

Signal	OC field	Control field	Note
O_QUIET	No transmission		
O_ACQUIRE	OC = IDLE	$o\_trig = 0$ , IB-9 = 1	User Data: Denied VOC: PSD_REFS command <i>eoc</i> : Denied
O_TRIG	OC = IDLE	$o\_trig = 1$ , IB-7 to IB-9 = 0	User Data: Applicable (Note 1) VOC: IDLE <i>eoc</i> : Denied
O_DATA	OC = valid message	$o\_trig = 0$ , IB-7 to IB-9 = 0	User Data: Applicable (Note 1) VOC: Applicable <i>eoc</i> : Applicable (Note 1)
R_QUIET	No transmission		
R_ACQUIRE	OC = IDLE	$r\_trig = 0$ , $r\_flag = 0$ , IB-9 = 1	User Data: Denied VOC: IDLE <i>eoc</i> : Denied Variable transmit level (Note 3)
R_TRIG	OC = IDLE	$r\_trig = 1$ , $r\_flag = 0$ , IB-7 to IB-9 = 0	User Data: Applicable (Note 1) VOC: IDLE <i>eoc</i> : Denied
R_DATA	OC = valid message	$r\_trig = 0$ , $r\_flag = 0/1$ (Note 2) IB-7 to IB-9 = 0	User Data: Applicable (Note 1) VOC: Applicable <i>eoc</i> : Applicable (Note 1)
NOTE 1 – User data throughput is optional if the link is in <i>Idle</i> state.			
NOTE 2 – See detailed description on $r\_flag$ setting in I.4.3.7.			
NOTE 3 – Set to support the upstream startup power back-off as described in I.4.3.5.			

The following timers listed in Table I.27 are involved in the VTU-activation/deactivation process.

**Table I.27/G.993.1 – VTU-state machine timers**

Timer	Function	Value
$t_{p_o}$	Duration of the O_QUIET signal detection at VTU-O to complete the O_POWERUP state.	$10\text{ ms} \leq t_{p_o}, t_{p_r} \leq 100\text{ ms}$
$t_{p_r}$	Duration of the R_QUIET signal detection at VTU-R to complete the R_POWERUP state.	
$t_{l_r}$	DS equalizer convergence time-out	4 s
$t_{l_o}$	US equalizer convergence time-out	4 s
$t_{2_o}$	Time-out for VTU-O activation process	Depends on startup type: T1 for <i>Cold-Start</i> , T2 for <i>Warm-Start</i> , T3 for <i>Warm-Resume</i> , T4 for <i>Resume-on-Error</i> , T4+T5 following the CHANGE VOC message
$t_{2_r}$	Time-out for VTU-R activation process	



**Table I.27/G.993.1 – VTU-state machine timers**

Timer	Function	Value
$t_{3\_o}$	Time-out for VTU-O trigger handshake	1000 ms
$t_{3\_r}$	Time-out for VTU-R trigger handshake	100 ms
$t_{4\_o}$	Time-out to recover VTU-O frame synchronization	T5 (200 ms; see 11.1.4 of Part 1)
$t_{4\_r}$	Time-out to recover VTU-R frame synchronization	T5 (200 ms; see 11.1.4 of Part 1)

**I.4.3.5 Startup power back-off**

The startup power back-off shall be performed during Cold-start only by applying a frequency independent (flat) transmit PSD reduction on the upstream carriers at the beginning of Cold-Start activation (see I.4.1.2 and I.4.3.7). The VTU-R receiver shall resolve the value of the transmit PSD template for each upstream carrier ( $TxPSD\_U$ ) autonomously (with no assistance from the VTU-O) by analysing the received downstream signal from and using the following rule:

$$TxPSD = PSD\_REF(f_c) + LOSS(f_c) - LOSS\_CORR$$

where:

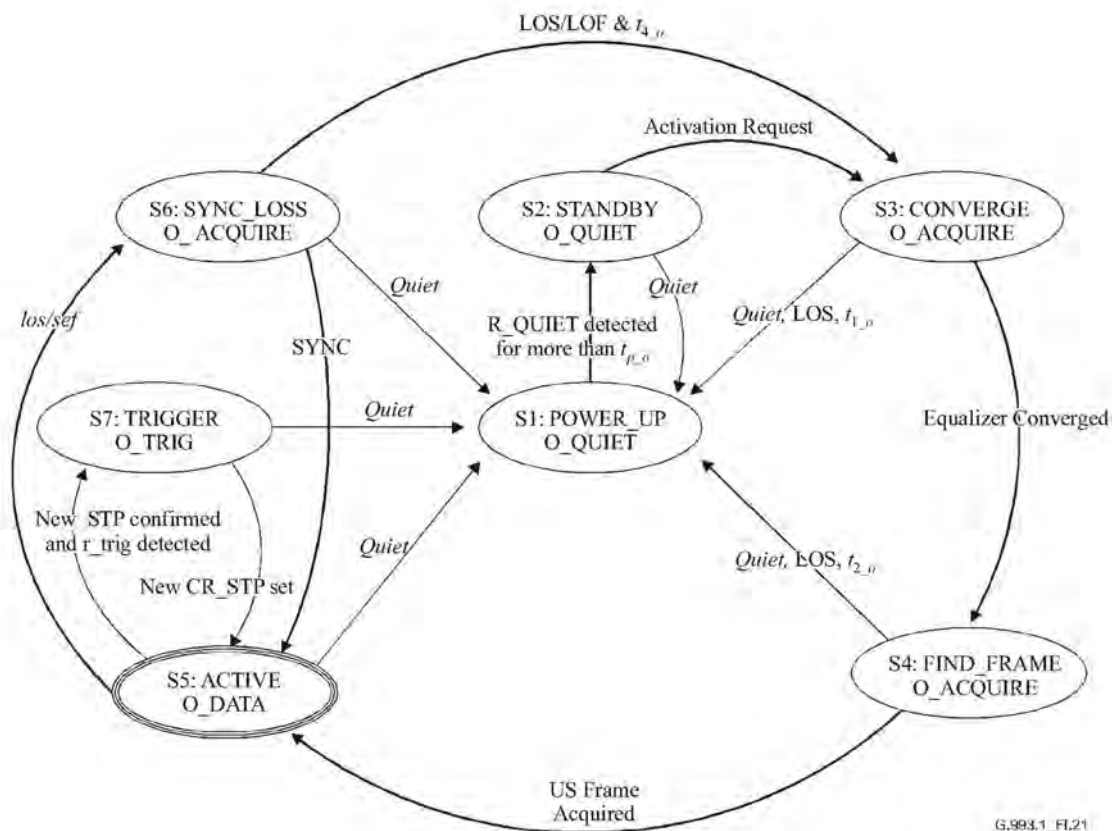
- $PSD\_REF$ ,  $LOSS$  are the variables defined in 6.3.2;
- $f_c$  is the centre frequency of the upstream carrier;
- $LOSS\_CORR$  is an additional reduction of the upstream transmit PSD which compensates for possible inaccuracy in the estimated value of the electrical length of the loop. If the resolved value  $TxPSD\_U$  exceeds the limiting upstream template  $PSD_\theta$  defined in 6.3.2, the value of the limiting template shall be used.

The recommended value of  $LOSS\_CORR$  is 3 dB for the regions where bridged taps is not an issue, and 6 dB for regions where bridged taps are expected. The specified value of  $LOSS\_CORR$  is valid for the VDSL link transmission parameters used during *Cold-Start* and specified in I.4.2.1.2, Table I.23. For other transmission parameters the value of  $LOSS\_CORR$  may be revised based on the regionally specific issues.

**I.4.3.6 VTU-O state machine**

The VTU-O state machine is shown in Figure I.21. Each ellipsoid block in Figure I.21 represents a state and contains the state number ( $S1 - S7$ ) followed by the state title. The type of transmit signal, while residing in the state, is placed below the state title.





**Figure I.21/G.993.1 – VTU-O activation/deactivation state machine**

**S1: O POWERUP**

This state is the initial state of the state machine. It corresponds to the start of the activation process and shall be entered in the following cases:

- a *QUIET* control signal or a Power-up request is applied. This is the first step in pending *Cold-Start* or *Warm-Start* activation, as shown by Figure I.19.
- Loss of upstream signal (*US\_LOS*) is detected while in states *S3*, *S4*, or time-out of states *S3*, *S4* occurs. This *S1* entry follows a failed activation attempt and is the first step in a pending re-activation attempt of the type specified by Figure I.19.

In state *S1*, the VTU-O shall transmit O\_QUIET. The VTU-O transmitter and receiver shall be configured with the STP stored in CR\_STPM. The VTU-O shall enter state *S2* if loss of the received upstream signal (*US LOS*) is detected for more than  $t_{p\_o}$  ms.

NOTE – The definition of *US LOS* is specified in I.3.1 (*LOS primitive*).

**S2: O STANDBY**

In state *S2* the VTU-O shall transmit *O\_QUIET* and wait for an activation request. The latter could be either the *CON* control signal if the link is activated from the VTU-O, or detection of the upstream received signal energy if the link is activated from the VTU-R. The *DISCON* control signal, if enabled, shall override any activation request from the VTU-R.

Once the activation request is performed, timer  $t_0$  shall be started from zero and state  $S3$  shall be entered. If *QUIET* is applied while in this state, the VTU-O shall return to state  $S1$ .

NOTE – Timer  $t_O$  is intended for monitoring of the VTU-R synchronization process.

**S3: O\_CONVERGE**

This state is entered from state *S2* following an activation request, or from state *S6* following a non-recovered synchronization loss. In state *S3* the VTU-O shall transmit the O\_ACQUIRE signal while attempting to converge the upstream equalizer(s). The IB-9 (*rdi*) shall be set to 1 indicating that the upstream direction is not synchronized.

NOTE – The transition from *S6* to *S3* corresponds to initiation of a *Resume-On-Error* activation attempt. It also includes the case when synchronization loss is due to a change in the upstream transmission parameters through a CHANGE VOC message.

The VTU-O should converge its upstream equalizer(s) before the timer  $t_O$  reaches  $t_{p_o}$  ms. If convergence is not achieved within this time, the VTU-O shall return to state *S1*. If convergence is reached before this time, the VTU-O shall enter state *S4*, without waiting for the full time-out period to elapse. If *QUIET* is applied or if *US\_LOS* occurs while in this state, VTU-O shall return to state *S1*.

**S4: O\_FINDFRAME**

While in state *S4*, the VTU-O shall transmit O\_ACQUIRE and IB-9 (*rdi*) shall be set to 1, indicating that the upstream direction is not synchronized yet. In state *S4*, the VTU-O shall process the received upstream signal to acquire the transmission frame (see I.1.2, "Transmission frame"). The VTU-O shall enter state *S5* as soon as the frame acquisition is complete and stable for at least 100 ms. The VTU-O shall return to state *S1* if frame acquisition is not complete before the timer  $t_O$  reaches  $t_{2_o}$  ms, or if *QUIET* is applied, or if *US\_LOS* occurs while in this state.

**S5: O\_ACTIVE**

The VTU-O shall reside in this state while the upstream channel is acquired. While in *S5*, the VTU-O shall transmit O\_DATA, and the state of the link is either *Steady-State Transmission* or *Idle*.

In *S5* the VTU-O may transmit VOC messages to modify CR\_STP, WS\_STP or I\_STP if required by the VTU-O management entity. If the link is in *Idle* state, the VTU-O shall also track the *Back-to-Service* request from the VTU-R by monitoring the *r\_flag* bits in the received transmission frame header. After *r\_flag* = 1 is detected, the VTU-O shall transmit the BTSERV VOC message to confirm the request. If the BTSERV message is transmitted successfully, the B\_SERV control signal shall be applied to initiate the transition of the link from *Idle* state back to *Steady-State Transmission* state.

To perform a generic CR\_STP modification, a CHNG\_PRM control signal shall be applied. It forces the VTU-O to transmit VOC messages containing new values of transmission parameters. Once all the necessary new parameter values are successfully transmitted (no ECHO response from the VTU-R on the requested parameter change is UTC), the VTU-O shall transmit a CHANGE VOC message. The CHANGE message confirms that both the VTU-O and VTU-R are ready to change their transmission parameters for a new parameter setting. After the CHANGE message is transmitted successfully, the VTU-O shall wait for reception of the upstream signal R\_TRIG by monitoring the *r\_trig* bits in the received transmission frame header. Once the received value *r\_trig* = 1 is detected, the VTU-O shall move to state *S7*.

If the VTU-O is in *Idle* state and a B\_SERV Control signal is applied (initiated either by the VTU-O or upon *r\_flag* = 1 reception), the VTU-O shall transmit a BTSERVC VOC message. The BTSERVC confirms that both the VTU-O and VTU-R are ready to change their transmission parameters to WR\_STP to return the link back to *Steady-State Transmission* state from *Idle* state. After the BTSERVC message is transmitted successfully, the VTU-O shall wait for reception of the upstream signal R\_TRIG by monitoring the *r\_trig* bits in the received transmission frame header. Once the received value *r\_trig* = 1 is detected, the VTU-O shall move to state *S7*.



If the VTU-O is in *Steady-State Transmission* state and an *I\_REQ* Control signal is applied, the VTU-O shall transmit a *IDLEREQ* VOC message. The *IDLEREQ* confirms that both the VTU-O and VTU-R are ready to change their transmission parameters with *I\_STP* to pull the link into *Idle* state from *Steady-State Transmission* state. After the *IDLEREQ* message is transmitted successfully, the VTU-O shall wait for reception of the upstream signal *R\_TRIG* by monitoring the *r\_trig* bits in the received transmission frame header. Once the received value *r\_trig* = 1 is detected, the VTU-O shall move to state *S7*.

If *R\_TRIG* is not received in  $t_{3_o}$  ms after any *CHANGE*, *BTSERVC* or *IDLEREQ* message is transmitted successfully, the VTU-O shall make no changes in *CR\_STP* and shall remain in *ACTIVE* state. If *US\_los* or *US\_sef* occurs while in this state, the VTU-O shall enter state *S6*. If *QUIET* is applied, the VTU-O shall return to state *S1*.

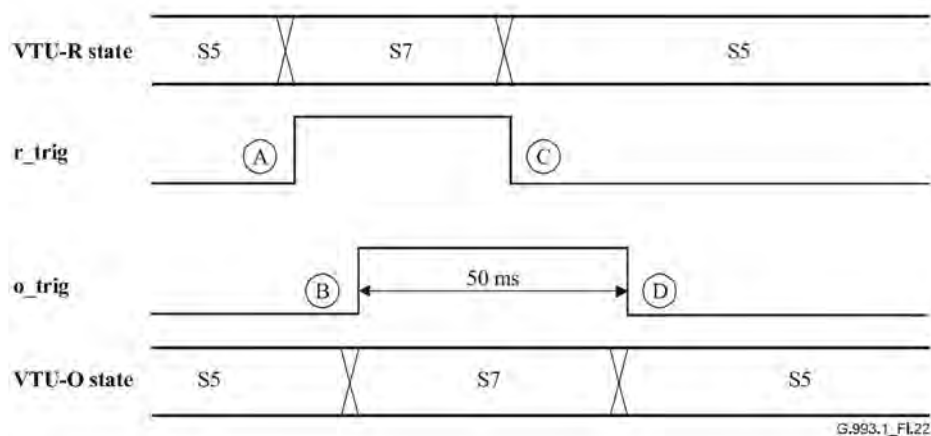
#### **S6: O\_SYNC LOSS**

In this state the VTU-O attempts to recover the lost transmission frame synchronization. During this state *O\_ACQUIRE* shall be transmitted to inform the VTU-R of the VTU-O synchronization loss by setting *IB-9 (rdi)* = 1. After synchronization is recovered, the VTU-O shall return to state *S5*. If synchronization is not recovered during the time-out interval of  $t_{4_o}$  ms, the VTU-O shall move to state *S3* to initiate a *Resume-On-Error* activation request. The VTU-O shall move to state *S1* if *QUIET* is applied.

#### **S7: O\_TRIGGER**

In state *S7*, the VTU-O shall transmit the *O\_TRIGGER* signal with *o\_trig* = 1 for  $50\text{ ms} \pm 1\text{ ms}$ . Following this the VTU-O shall overwrite *CR\_STP* with a new parameter setting, with *WR\_STP*, or with *I\_STP*, depending on whether the *CHANGE*, *BTSERVC*, or *IDLEREQ* VOC message, respectively, was last transmitted. Then the VTU-O shall make the corresponding changes to its transmission parameters, and return to state *S5* with a new *CR\_STP* parameter setting. Upon entering *S5*, *RE\_STP* shall be automatically overwritten with *CR\_STP*. If *QUIET* is applied, the VTU-O shall return to state *S1*.

NOTE – Transmission of *o\_trig* is to synchronize transmission parameter modification at the VTU-R with the same modification at the VTU-O. The timing diagram of the VTU-O to VTU-R interaction during the *O/R\_TRIGGER* state is presented in Figure I.22. In accordance with Figure I.22, the VTU-R executes the parameter change after point "C" and the VTU-O executes the parameter change after point "D". Thus, the maximum difference between parameter modification at the VTU-O and VTU-R cannot exceed 50 ms.



*Trigger transitions:*

- A) CHANGE/BTSERV/IDLEREQ VOC confirmed, VTU-R enters state S7.
- B) CHANGE /BTSERV/IDLEREQ VOC confirmed, VTU-O detects  $r\_trig = 1$ , VTU-O enters state S7.
- C) VTU\_R detects  $o\_trig = 1$  and enters S5.
- D) 50 ms after entering S7, VTU-O enters S5.

**Figure I.22/G.993.1 – Trigger transitions following CHANGE, BTSERV and IDLEREQ VOC messages**

#### **1.4.3.7 VTU-R state machine**

The VTU-R state machine is shown in Figure I.23. The conventions for interpreting this figure are the same as those for Figure I.21.

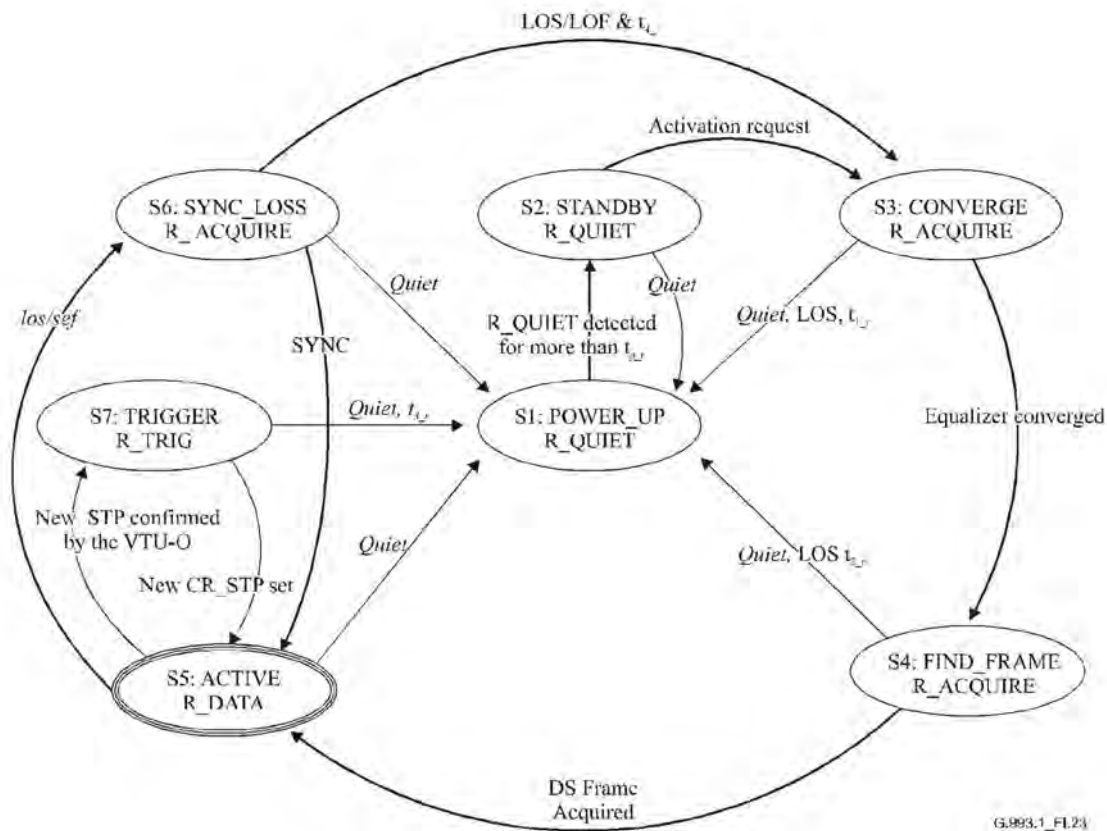


Figure I.23/G.993.1 – VTU-R activation/deactivation state machine

### S1: R\_POWERUP

This state is the initial state of the state machine. It corresponds to the start of the process and shall be entered in the following cases:

- a *QUIET* control signal or a Power-up request is applied. This is the first step in pending a *Cold-Start* or *Warm-Start* attempt, as shown by Figure I.19.
- Loss of downstream signal (*DS\_LOS*) is detected while in states *S3*, *S4*, or time-out of states *S3*, *S4* occurs. This *S1* entry follows a failed activation attempt and is the first step in a pending re-activation attempt of the type specified by Figure I.19.

In state *S1* the VTU-R shall transmit *R\_QUIET*. The VTU-R transmitter and receiver shall be configured with the STP stored in *CR\_STPM*. The VTU-R shall enter state *S2* if loss of the received downstream signal (*DS\_LOS*) is detected for more than  $t_{p,r}$  ms.

NOTE – The definition of *DS\_LOS* is specified in I.3.1 (*LOS* primitive).

### S2: R\_STANDBY

In state *S2* the VTU-R shall transmit *R\_QUIET* and wait for an activation request. The latter could be either the *CON* control signal, if the link is activated from the VTU-R, or detection of the downstream received signal energy, if the link is activated from the VTU-O. Once the activation request is performed, timer  $t_R$  shall be started from zero, and state *S3* is entered. If *QUIET* is applied while in this state, the VTU-R shall return to state *S1*.

NOTE – Timer  $t_R$  is used for monitoring of the VTU-O synchronization process.



### S3: R\_CONVERGE

This state is entered from state *S2* following an activation request, or from state *S6* following a non recovered synchronization loss. In state *S3* the VTU-R shall transmit the R\_ACQUIRE signal while attempting to converge the downstream equalizer(s). The IB-9 (*rdi*) bit shall be set to 1 indicating that the downstream direction is not synchronized.

NOTE – The transition from *S6* to *S3* corresponds to initiation of a *Resume-On-Error* activation attempt. It also includes the case when synchronization loss is due to a change in the upstream transmission parameters through a CHANGE VOC message.

The VTU-R should converge its downstream equalizer(s) before the timer  $t_R$  reaches  $t_{1_r}$  ms. If convergence is not achieved within this time the VTU-R shall return to state *S1*. If convergence is reached before this time, the VTU-R shall enter state *S4*, without waiting for the full time-out period to elapse. If *QUIET* is applied or if *DS\_LOS* occurs while in this state, the VTU-R shall return to state *S1*.

If state *S3* is entered from state *S2*, an upstream power back-off (UPBO) procedure (see 6.3.2) shall be applied. Upon entering state *S3* the VTU-R shall start to transmit the R\_ACQUIRE signal with the default (low) power level, as specified in I.4.3.5. In the beginning of the downstream equalizer converging, the required UPBO shall be calculated, as described in 0, and the R\_ACQUIRE signal power level shall be set to the nominal value, including the UPBO. The functional diagrams describing activation from both the VTU-O and the VTU-R are presented in Figures I.24 and I.25, respectively.

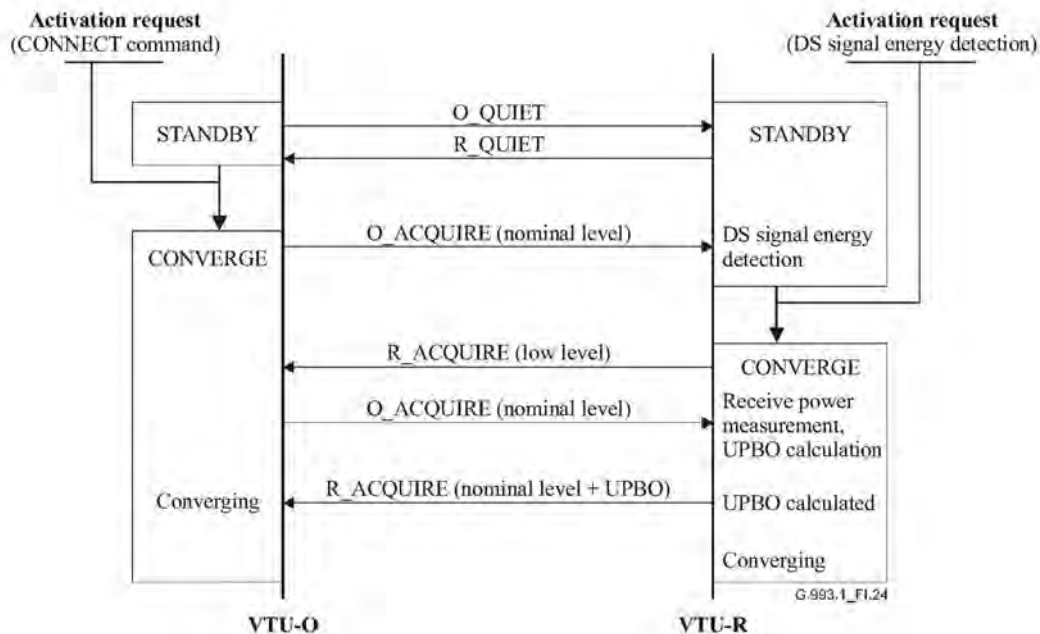


Figure I.24/G.993.1 – Activation from the VTU-O

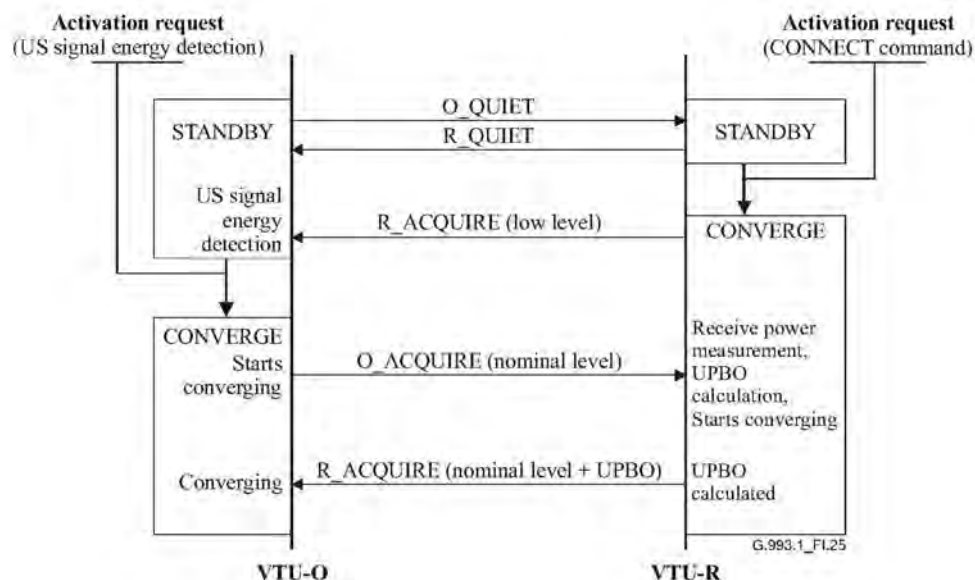


Figure I.25/G.993.1 – Activation from the VTU-R

**S4: R\_FINDFRAME**

While in state *S4* the VTU-R shall transmit *R\_ACQUIRE* and *IB-9 (rdi)* bit shall be set to 1 indicating that the downstream direction is not synchronized yet. In state *S4* the VTU-R shall process the received downstream signal to acquire the transmission frame (see I.1.2). The VTU-R shall enter state *S5* as soon as frame acquisition is complete and stable for at least 100 ms. The VTU-R shall return to state *S1* if frame acquisition is not complete before  $t_R$  reaches  $t_{2,r}$  ms, or if *QUIET* is applied, or if *DS\_LOS* occurs while in this state.

**S5: R\_ACTIVE**

The VTU-R resides in this state while the downstream channel is acquired. While in *S5* the VTU-R shall transmit *R\_DATA* and the state of the link is either *Steady State Transmission* or *Idle*.

In *S5* the VTU-R may receive VOC messages delivering modified transmission parameters values for *CR\_STP*, *WS\_STP* or *I\_STP*, as directed by the VTU-O. If a *B\_SERV* control signal is applied, the VTU-R shall transmit  $r\_flag = 1$  and shall wait for the successful reception of the BTSEV VOC message, which confirms that the *B\_SERV* signal applied in the VTU-R was received by the VTU-O. If the VTU-R successfully receives the *CHANGE*, *BTSEV*, or *IDLEREQ* VOC message, it shall enter state *S7*. If *DS\_los* or *DS\_sef* occurs while in this state, VTU-R shall enter state *S6*. If *QUIET* is applied VTU-R shall return to state *S1*.

**S6: R\_SYNC LOSS**

In this state the VTU-R attempts to recover the lost transmission frame synchronization. During this state *R\_ACQUIRE* shall be transmitted to inform the VTU-O of the VTU-R synchronization loss by setting *IB-9 (rdi)* = 1. After synchronization is recovered, the VTU-R shall return to state *S5*. If synchronization is not recovered during the time-out interval of  $t_{4,r}$  ms, the VTU-R shall move to state *S3* to initiate a *Resume-On-Error* activation request. The VTU-R shall move to state *S1* if *QUIET* is applied.

**S7: R\_TRIGGER**

In state *S7* the VTU-R shall transmit the *R\_TRIG* signal with  $r\_trig = 1$ , and shall monitor the  $o\_trig$  bit in the received transmission frames. Once  $o\_trig = 1$  is detected, the VTU-R shall overwrite *CR\_STP* with a new parameter setting, with *WR\_STP*, or with *I\_STP*, depending on



whether the CHANGE, BTSERV or IDLEREQ VOC message, respectively, was last transmitted. Then the VTU-R shall make the corresponding changes in its transmission parameters, and shall return to state *S5* with a new CR\_STP parameter setting. Upon entering *S5*, RE\_STP shall be automatically overwritten to CR\_STP. If *o\_trig* = 1 is not detected within the time-out interval of  $t_{3,r}$  ms after entering state *S7*, the VTU-R shall return to state *S1*. If *QUIET* is applied, the VTU-R shall return to state *S1*.

#### **1.4.3.8 Two-step activation**

Both the VTU-O and the VTU-R may support a two-step activation process:

Step 1: Activation with 4-point constellation.

Step 2: Modifying the constellation to the required size using a standard CR-STP modification procedure (see 9.2.2.2).

The two-step activation shall use the standard activation diagram described in 9.1 and the standard VTU state machine described in 1.4.3.6 and 1.4.3.7 for both steps. It shall be performed in the following sequence:

- 1) Start the link and reach steady-state transmission with DF\_STP.
- 2) Assign the first-step transmission profile with all the transmission parameters equal to the parameters of the required transmission profile, except setting the constellation equal to 4 for both carriers in both directions.
- 3) Modify CR\_STP from DF\_STP to the first-step transmission profile using the CHANGE command and reach steady-state transmission.
- 4) Assign constellation size equal to the original constellation size of the required transmission profile (by CONSTEL command).
- 5) Modify CR\_STP to the assigned constellation size using the CHANGE command and reach steady-state transmission.

Any performance monitoring VOC messages are allowed between the listed five steps. If the VTU-R is capable for 2-step activation only, the constellation size applied for WS\_STP shall always be set to QAM-4.

#### **1.4.4 G.994.1 Handshake bit definitions**

##### **1.4.4.1 CL messages**

A VTU-O wishing to indicate this annex's capabilities in a G.994.1 CL message shall do so by setting to ONE at least one of the Standard Information Field {NPar(2) or SPar(2)} G.993.1 – Annex I bits as defined in and shown in Table 11.61/G.994.1 and Table 11.62/G.994.1. For each G.993.1 – Annex I {SPar(2)} bit set to ONE, a corresponding {NPar(3)} field shall also be present (see 9.4/G.994.1). The G.994.1 CL message {NPar(2) and SPar(2)} fields are defined in Tables I.28 and I.29.

**Table I.28/G.993.1 – Annex I VTU-O CL message NPar(2) bit definitions**

<b>G.994.1 bit</b>	<b>Definition</b>
OptUp	If set to ONE, signifies that the VTU-O can be configured to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission.
OptDn	If set to ONE, signifies that the VTU-O can be configured to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission.
PSDRed	If set to ONE, signifies that the VTU-O can be configured to reduce the PSD in the frequency region below 1.104 MHz.

**Table I.28/G.993.1 – Annex I VTU-O CL message NPar(2) bit definitions**

<b>G.994.1 bit</b>	<b>Definition</b>
PTM	If set to ONE, signifies that the VTU-O can be configured for PTM transport.
ATM	If set to ONE, signifies that the VTU-O can be configured for ATM cell transport (see Annex G).
EOC-Clear	If set to ONE, signifies that the VTU-O supports transmission and reception of G.997.1 OAM frames.

**Table I.29/G.993.1 – Annex I VTU-O CL message SPar(2) bit definitions**

<b>G.994.1 bit</b>	<b>Definition</b>
DF_STP	If set to ONE, signifies that the VTU-O CL message transmitted DF_STP shall be used.

**I.4.4.2 VTU-O MS messages**

A VTU-O selecting this annex's mode of operation in a G.994.1 MS message shall do so by setting to ONE the appropriate Standard Information Field {NPar(2) or SPar(2)} G.993.1 – Annex I bits as defined in Table 11.61/G.994.1 and Table 11.62/G.994.1. For each G.993.1 – Annex I {SPar(2)} bit set to ONE, a corresponding {NPar(3)} field shall also be present (see 9.4/G.994.1). The G.994.1 MS message {NPar(2)} fields corresponding to the {SPar(1)} bit are defined in Tables I.30 and I.31.

**Table I.30/G.993.1 – Annex I VTU-O MS message NPar(2) bit definitions**

<b>G.994.1 bit</b>	<b>Definition</b>
OptUp	If set to ONE, signifies to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission. In an MS message, only one of OptUp and OptDn may be set to ONE.
OptDn	If set to ONE, signifies to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission. In an MS message, only one of OptUp and OptDn may be set to ONE.
PSDRed	If set to ONE, signifies to reduce the PSD in the frequency region below 1.104 MHz.
PTM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for PTM transport.
ATM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for ATM cell transport.
EOC-Clear	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R may transmit and receive G.997.1 OAM frames.



**Table I.31/G.993.1 – Annex I VTU-O MS message SPar(2) bit definitions**

<b>G.994.1 bit</b>	<b>Definition</b>
DF_STP	If set to ONE, signifies that the VTU-O CL message transmitted DF_STP shall be used.

**1.4.4.3 VTU-R CLR messages**

A VTU-R wishing to indicate this annex's capabilities in a G.994.1 CLR message shall do so by setting to ONE at least one of the Standard Information Field {NPar(2) or SPar(2)} G.993.1 – Annex I bits as defined in Table 11.61/G.994.1 and Table 11.62/G.994.1. For each G.993.1 – Annex I {SPar(2)} bit set to ONE, a corresponding {NPar(3)} field shall also be present (see 9.4/G.994.1). The G.994.1 CLR message {NPar(2) and SPar(2)} fields are defined in Tables I.32 and I.33.

**Table I.32/G.993.1 – Annex I VTU-R CLR message NPar(2) bit definitions**

<b>G.994.1 bit</b>	<b>Definition</b>
OptUp	If set to ONE, signifies that the VTU-R can be configured to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission.
OptDn	If set to ONE, signifies that the VTU-R can be configured to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission.
PSDRed	If set to ONE, signifies that the VTU-R can be configured to reduce the PSD in the frequency region below 1.104 MHz.
PTM	If set to ONE, signifies that the VTU-R can be configured for PTM transport.
ATM	If set to ONE, signifies that the VTU-R can be configured for ATM cell transport.
EOC-Clear	If set to ONE, signifies that the VTU-R supports transmission and reception of G.997.1 OAM frames.

**Table I.33/G.993.1 – Annex I VTU-R CLR message SPar(2) bit definitions**

<b>G.994.1 bit</b>	<b>Definition</b>
DF_STP	Shall be set to ONE.

**1.4.4.4 VTU-R MS messages**

A VTU-R selecting this annex's mode of operation in a G.994.1 MS message shall do so by setting to ONE the appropriate Standard Information Field {NPar(2) or SPar(2)} G.993.1 – Annex I bits as defined in Table 11.61/G.994.1 and Table 11.62/G.994.1. For each G.993.1 – Annex I {SPar(2)} bit set to ONE, a corresponding {NPar(3)} field shall also be present (see 9.4/G.994.1). The G.994.1 MS message {NPar(2)} fields corresponding to the {SPar(1)} bit are defined in Tables I.34 and I.35.

**Table I.34/G.993.1 – Annex I VTU-R MS message NPar(2) bit definitions**

<b>G.994.1 bit</b>	<b>Definition</b>
OptUp	If set to ONE, signifies to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission. In an MS message, only one of OptUp and OptDn may be set to ONE.



**Table I.34/G.993.1 – Annex I VTU-R MS message NPar(2) bit definitions**

<b>G.994.1 bit</b>	<b>Definition</b>
OptDn	If set to ONE, signifies to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission. In an MS message, only one of OptUp and OptDn may be set to ONE.
PSDRed	If set to ONE, signifies to reduce the PSD in the frequency region below 1.104 MHz.
PTM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for PTM transport.
ATM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R shall be configured for ATM cell transport.
EOC-Clear	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Signifies that both VTU-O and VTU-R may transmit and receive G.997.1 OAM frames.

**Table I.35/G.993.1 – Annex I VTU-R MS message SPar(2) bit definitions**

<b>G.994.1 bit</b>	<b>Definition</b>
DF_STP	If set to ONE in CL message, shall be set to ONE.

**1.4.4.5 VTU-R MP messages**

A VTU-R proposing this annex's mode of operation in a G.994.1 MP message shall do so by setting to ONE the appropriate Standard Information Field {NPar(2) or SPar(2)} G.993.1 – Annex I bits as defined in Table 11.61/G.994.1 and Table 11.62/G.994.1. For each G.993.1 – Annex I {SPar(2)} bit set to ONE, a corresponding {NPar(3)} field shall also be present (see 9.4/G.994.1). The G.994.1 MP message {NPar(2) and SPar(2)} fields corresponding to the {SPar(1)} bit are defined in Tables I.36 and I.37.

**Table I.36/G.993.1 – Annex I VTU-R MP message NPar(2) bit definitions**

<b>G.994.1 bit</b>	<b>Definition</b>
OptUp	If set to ONE, signifies to propose to use the optional band from 25 to 138 kHz for upstream (VTU-R → VTU-O) transmission. In an MP message, only one of OptUp and OptDn may be set to ONE.
OptDn	If set to ONE, signifies to propose to use the optional band from 25 to 138 kHz for downstream (VTU-O → VTU-R) transmission. In an MP message, only one of OptUp and OptDn may be set to ONE.
PSDRed	If set to ONE, signifies to propose to reduce the PSD in the frequency region below 1.104 MHz.
PTM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Proposes that both VTU-O and VTU-R shall be configured for PTM transport.

**Table I.36/G.993.1 – Annex I VTU-R MP message NPar(2) bit definitions**

<b>G.994.1 bit</b>	<b>Definition</b>
ATM	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Proposes that both VTU-O and VTU-R shall be configured for ATM cell transport.
EOC-Clear	Set to ONE, if and only if this bit was set to ONE in both the last previous CL message and the last previous CLR message. Proposes that both VTU-O and VTU-R may transmit and receive G.997.1 OAM frames.

**Table I.37/G.993.1 – Annex I VTU-R MP message SPar(2) bit definitions**

<b>G.994.1 bit</b>	<b>Definition</b>
DF_STP	If set to ONE in CL message, shall be set to ONE.

## **1.5 Complementary information on QAM implementation (informative)**

### **1.5.1 Spectral allocation of the transmit signal**

In accordance with transmit filter characteristics, described in 1.2.2.3.2.2, all carriers shall have a square-root raised-cosine power spectral shaping with  $\alpha$  excess bandwidth. Thus, the lowest frequency ( $f_{LOW}$ ) and the highest frequency ( $f_{HIGH}$ ) for each carrier should be calculated as:

$$f_{LOW} = f_C - 0.5(1 + \alpha \times SR)$$

$$f_{HIGH} = f_C + 0.6 \times SR$$

where  $f_C$  and  $SR$  are the carrier frequency and its symbol rate, respectively. The 3-dB bandwidth of a carrier occupies the frequency range between  $f_C - 0.5 \times SR$  and  $f_C + 0.5 \times SR$ .

### **1.5.2 Transport capability of the PMS-TC**

The Aggregate Transport Capability (ATC) of the PMS-TC is determined by the format of the transmission frame. The ATC for the Fast channel, the Slow channels and the total ATC, respectively, are calculated as follows:

$$ATC\_f = TR \times \frac{2(F - RF)}{405} \text{ Mbit/s}$$

$$ATC\_s = TR \times \frac{2(S - 19)}{405} \text{ Mbit/s}$$

$$ATC = TR \times \frac{362}{405} \text{ Mbit/s}$$

where  $TR$  [Mbit/s] is the total bit rate of the applied transmission profile in the given direction.

The maximum ATC of the Operations channel (shared between the *eoc* and VOC) is calculated as:

$$ATC\_OC = TR \times \frac{6}{405} \text{ Mbit/s}$$

The maximum ATC of the *eoc* channel equals to  $0.66 \times ATC\_OC$ .

If the ATC of either the Slow or the Fast channel is shared among different services (multi-user configuration), the ATC intended for a particular service  $k$  is calculated as:

$$ATC\_k = TR \times \frac{2K}{405} \text{ Mbit/s}$$

where  $K$  denotes the number of octets (in either the Slow or the Fast codeword) dedicated for this service (see I.1.2.3).

### I.5.3 Transmission frame delineation algorithm

This transmission frame delineation algorithm is based on Sync\_Events (Syncword detection at the expected locations). The frame delineation state machine, comprising HUNT, PRESYNC and SYNC states, is shown in Figure I.26. In HUNT state frame synchronization is lost and the state machine attempts to acquire frame synchronization by searching the frame Sync\_Event. After the first Sync\_Event occurs the state machine moves from HUNT state to PRESYNC state. The state machine moves from PRESYNC state to SYNC state when Sync\_Event occurs consecutively at least  $n = 2$  times. If a violated Sync\_Event occurs during PRESYNC state, the state machine returns to HUNT state. The state machine moves from SYNC state to HUNT state when Sync\_Event is violated consecutively at least  $m = 6$  times.

NOTE – For data rates higher than 26 Mbit/s, the number of consecutively violated Sync\_Event to move from SYNC state to HUNT state should be at least  $m = 8$  times.

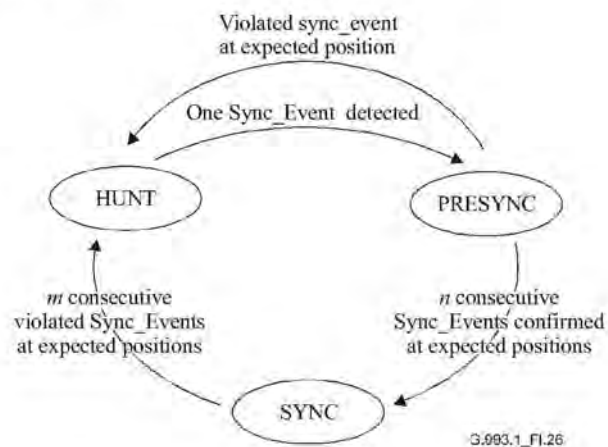


Figure I.26/G.993.1 – Frame delineation state machine

### I.5.4 Parameters of the interleaver

#### I.5.4.1 Parameters

The main characteristics of the interleaver are presented in Table I.38.



**Table I.38/G.993.1 – Interleaver characteristics**

Parameter	Value	Notes
Block Length ( $I$ )	$I = S/4, S/8, S/16$ [octets]	$S = PS + 19$ [octets]
Depth ( $D$ )	$D = M \times I + 1$ [octets]	$M = 0 - 64$ , programmable
Erasure Correction ( $E$ )	$E = \lfloor t \times I / S \rfloor \times (M \times I + 1)$ [octets]	$t = 8$ (RS error correction ability)
End-to-End Delay ( $DL$ )	$DL = M \times I \times (I - 1)$ [octets]	
Interleaver Memory Size	$MEM = M \times I \times (I - 1)/2$ [octets]	

NOTE – Symbol " $\lfloor \rfloor$ " indicates truncating to the lower integer.

The interleaver erasure correction  $E$  defines the maximum number of sequential corrupted octets in the data stream that can be corrected by the RS algorithm when interleaving is applied. Accordingly, the duration of noise pulses that the system is protected from can be calculated as  $E \times 8/R$ , where  $R$  is the bit rate of the transmit signal.

Some typical values of the interleaving parameters  $M$ ,  $E$  and of the end-to-end delay calculated for  $S/I = 8$ ,  $t = 8$  and different line bit rates are presented in Table I.39.

**Table I.39/G.993.1 – Interleaving parameters**

Line rate [Mbit/s]		1.62	3.24	6.48	12.96	25.92
Value of $N/I$		8				
250 $\mu$ sec of erasure correction	$M$ [octets]	2	4	8	16	32
	Delay [msec]	5.9				
500 $\mu$ sec of erasure correction	$M$ [octets]	4	8	16	32	64
	Delay [msec]	11.8				

#### 1.5.4.2 Implementation example

Interleaving is performed at the transmit side by writing the octets of the incoming Reed-Solomon codeword into a bank of  $I$  virtual shift registers numbered  $j = 0, 1, \dots, (I - 1)$ . The length of virtual shift register  $j$  in the interleaving memory is:  $M \times j$ .

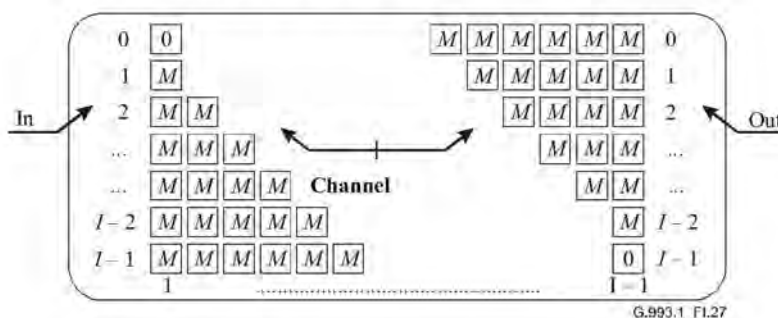
De-interleaving is performed at the receive side by writing the octets of the incoming codeword into a bank of  $I$  virtual shift registers numbered  $j = 0, 1, \dots, (I - 1)$ . The length of virtual shift register  $j$  in the de-interleaving memory is:  $M \times (I - 1 - j)$ .

The codeword is input either into the interleaving or de-interleaving memory by blocks of  $I$  octets at a time. The first octet from the codeword is written into the first shift register, the second octet into the second shift register, and so on, up to the register  $(I - 1)$ . This process is repeated  $S/I$  times until the complete codeword is input into the bank of shift registers.

The codeword is output from the interleaving or the de-interleaving memory by reading blocks of  $I$  octets at a time. The first octet from the codeword is read from the first shift register, the second octet from the second shift register and so on, up to register  $(I - 1)$ . This process is repeated  $S/I$  times until the complete codeword is extracted from the bank of shift registers.

Figure I.27 shows the structure of the interleaver. The  $I$  parallel branches, numbered  $0, 1, \dots, (I - 1)$  are implemented with a delay increments of  $M \times I$  octets per branch. Each branch is a shift register with a length of  $0, M \times I, 2M \times I, \dots, (I - 1) \times M \times I$  bytes. The de-interleaver is similar to the interleaver, but the branch indexes are reversed, so that the largest interleaver delay corresponds to

the smallest de-interleaver delay. De-interleaver synchronization is achieved by routing the first octet of an interleaved block of  $I$  bytes into the branch 0.



**Figure I.27/G.993.1 – Interleaver/de-interleaver implementation example**

## Appendix I

### UTOPIA implementation of the ATM-TC interface

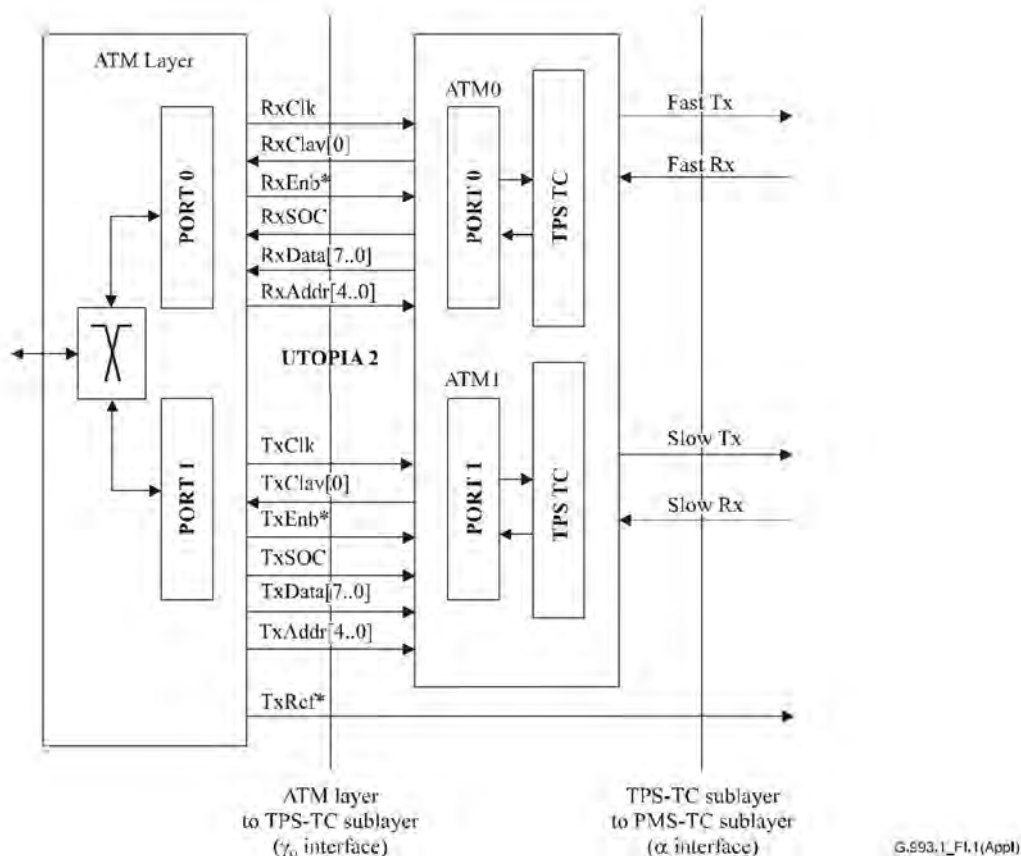
This Appendix describes the implementation of the interface between the ATM-specific TPS-TC sublayer and ATM layer at the VTU-O, called  $\gamma_O$ , interface in the G.993.1 reference model. The implementation is also applicable to the VTU-R.

The ATM layer performs cell multiplexing from and de-multiplexing to the appropriate physical port (i.e., latency path – Fast or Slow) based on the Virtual Path Identifier (VPI) and Virtual Connection Identifier (VCI), both contained in the ATM cell header. Configuration of the cell de-multiplexing process is done by ATM Layer management.

An ATM TPS-TC sublayer is provided for each latency path separately. ATM-TC functionality is described in Annex G.

The logical input and output interfaces at the reference point  $\gamma_O$  for ATM transport is based on the UTOPIA Level 2 interface with cell level handshake. The logical interface is given in Tables I.1 and I.2 and shown in Figure I.1. When a flow control flag is activated by the VTU-O (i.e., the VTU-O wants to transmit or receive a cell), the ATM layer initiates a cell Tx or cell Rx cycle (53 byte transfer). The VTU supports transfer of a complete cell within 53 consecutive clock cycles. The UTOPIA Tx and Rx clocks are mastered from the ATM layer. The same logical input and output interfaces based on the UTOPIA Level 2 interface can be used at the  $\gamma_R$  reference point in the VTU-R.





**Figure I.1/G.993.1 – UTOPIA-2 implementation of the ATM-TC application interface (VTU-O)**

**Table I.1/G.993.1 – UTOPIA Level 2 ATM interface signals for Tx**

Signal name	Direction	Description
<i>Transmit interface</i>		
TxCclk	ATM to PHY	Timing signal for transfer
TxClav[0]	PHY to ATM	Asserted to indicate that the PHY layer has buffer space available to receive a cell from the ATM layer (de-asserted 4 cycles before the end of the cell transfer)
TxEnb*	ATM to PHY	Asserted to indicate that the PHY layer must sample and accept data during the current clock cycle
TxSOC	ATM to PHY	Identifies the cell boundary on TxData
TxData[7..0]	ATM to PHY	ATM Cell Data transfer (8-bit mode)
TxAddr[4..0]	ATM to PHY	PHY device address to select the device that will be active or polled for TxClav status
TxRef*	ATM to PHY	Network Timing Reference (8-kHz timing signal) (only at $\gamma_0$ interface)

**Table I.2/G.993.1 – UTOPIA Level 2 ATM interface signals for Rx**

Signal Name	Direction	Description
<i>Receive interface</i>		
RxCk	ATM to PHY	Timing signal for transfer
RxCla <sub>v</sub> [0]	PHY to ATM	Asserted to indicate to the ATM layer that the PHY layer has a cell ready for transfer to the ATM layer (de-asserted at the end of the cell transfer)
RxEnb*	ATM to PHY	Asserted to indicate that the ATM layer will sample and accept data during the next clock cycle
RxSOC	PHY to ATM	Identifies the cell boundary on RxData
RxDat[7..0]	PHY to ATM	ATM Cell Data transfer (8-bit mode)
RxAdr[4..0]	ATM to PHY	PHY device address to select the device that will be active or polled for RxCla <sub>v</sub> status
RxRef*	PHY to ATM	Network Timing Reference (8-kHz timing signal) (only at γR interface)

More details on the UTOPIA Level 2 interface can be found in [ATMF].

## Appendix II

### International amateur radio bands

**Table II.1/G.993.1 – International amateur radio bands**

ITU-R Radio Regulations Region 1		ITU-R Radio Regulations Region 2		ITU-R Radio Regulations Region 3	
Band start [kHz]	Band stop [kHz]	Band start [kHz]	Band stop [kHz]	Band start [kHz]	Band stop [kHz]
1 810	1 850	1 800	2 000	1 800	2 000
3 500	3 800	3 500	4 000	3 500	3 900
7 000	7 100	7 000	7 300	7 000	7 100
10 100	10 150	10 100	10 150	10 100	10 150
14 000	14 350	14 000	14 350	14 000	14 350
18 068	18 168	18 068	18 168	18 068	18 168
21 000	21 450	21 000	21 450	21 000	21 450
24 890	24 990	24 890	24 990	24 890	24 990
28 000	29 700	28 000	29 700	28 000	29 700

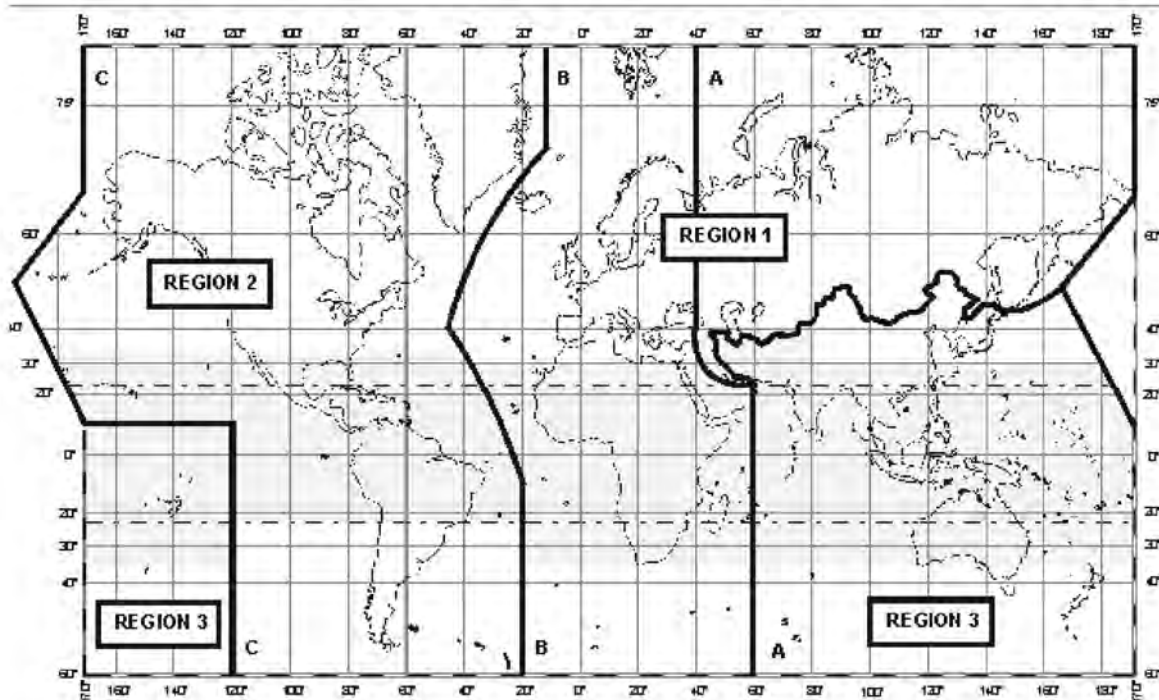


Figure II.1/G.993.1 – International amateur radio band regions

## Appendix III

### 8.625-kHz tone spacing

#### III.1 Scope

This appendix describes an MCM VDSL system operating in 8.625-kHz tone spacing mode. The primary application of the 8.625 kHz tone spacing could be for shorter loops where the 8.625-kHz tone spacing allows a smaller FFT/IFFT size, without additional changes to the PMD layer. The remainder of this appendix describes items, relative to the clauses in the main body of this Recommendation, which could be considered for an MCM VDSL system operating with 8.625-kHz tone spacing.

#### III.2 PMD functional characteristics

The PMD layer is implemented as defined in 9.2 using  $\Delta f = 8.625$  kHz.

NOTE 1 – This mode is targeted to loops less than 600 metres. Therefore, the typical cyclic extension lengths presented in 9.2.2 will be sufficient.

NOTE 2 – Clause 9.2.3.4 provides an optional mode for the users in a binder to synchronize. This mode is used to mitigate the effects of the NEXT due to the side lobes of the other users in that binder. Assuming that there exists a mix of 8.625- and 4.3125-kHz carrier spaced systems in a binder, given all-users-synchronization option is deployed, it is easily shown that 4.3125-kHz carrier spaced signals are orthogonal to 8.625-kHz carrier spaced signals in the opposite direction. However, the reverse is not true, i.e., 4.3125-kHz spaced tones could be affected by the 8.625-kHz spaced tones in the opposite direction. Therefore, service providers may choose not to utilize 8.625-kHz tone spacing where binder synchronization



is used. Otherwise, in asynchronous operation mode, two systems using different tone spacing do not disturb each other more than two systems using 4.3125-kHz tone spacing.

### III.3 Transmission Convergence (TC) sublayer

The TC layer of the 8.625-kHz tone spacing mode will follow 7 and 8, with the exception of the modification of the framing definition in 8.5.1, as presented in III.3.1.

#### III.3.1 Frame description

When using 8.625-kHz tone spacing, a TC layer data frame is a set of bytes carried by two DMT frames (i.e., DMT symbols). Otherwise, the framing description is the same as the 4.3125-kHz frame description.

### III.4 Initialization

Upon completion of some negotiation to indicate mutual support for 8.625-kHz tone spacing (further referred to as "First Negotiation"), the "ES" phase is entered. The "First Negotiation" procedure is beyond the scope of this appendix. The timeline of the ES phase is shown in Figure III.1. The names of the newly defined SOC messages and symbol types have the suffix 'ES' and are described in Table III.1.

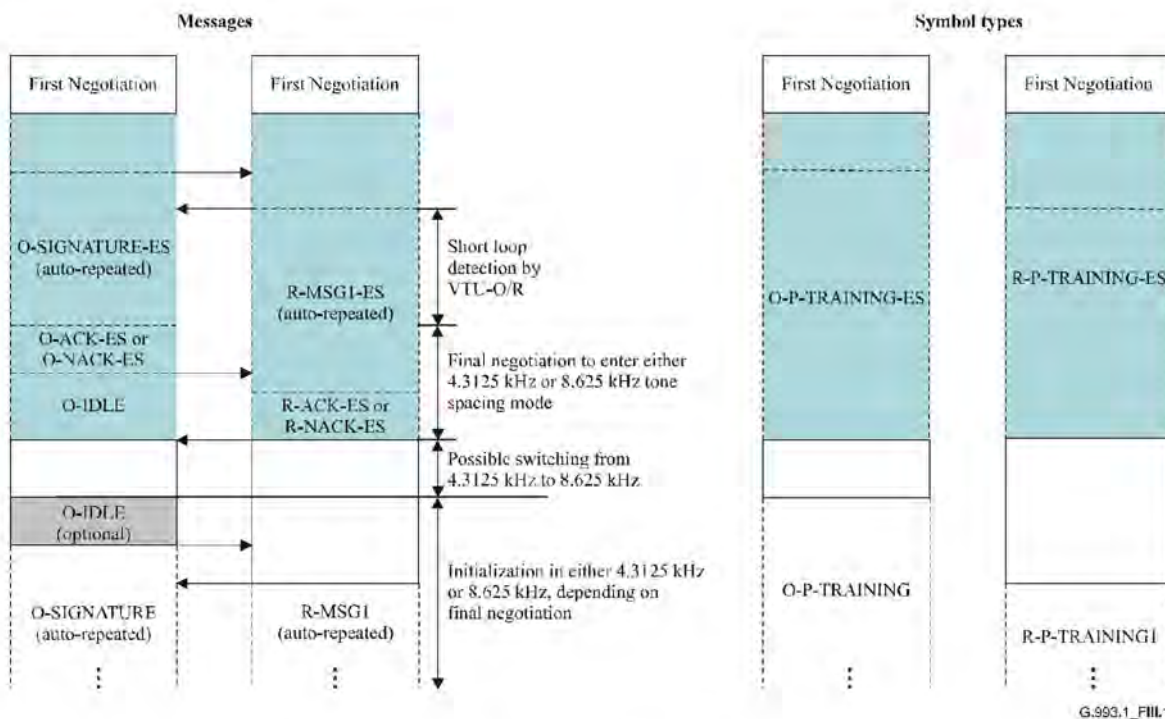


Figure III.1/G.993.1 – Timeline of ES phase

**Table III.1/G.993.1 – Message codes for the SOC messages used in the ES phase**

SOC Message	Message code
O/R-ACK-ES	0x33 (Note)
O/R-NACK-ES	0xCC (Note)
O-SIGNATURE-ES	0x31
R-MSG1-ES	0xB1
NOTE – This is the entire payload of the message.	

During the ES phase, short loop detection and final mode negotiation are performed. The VTU-O initiates the ES phase by transmitting the symbol O-P-TRAINING-ES. The message O-SIGNATURE-ES is sent in parallel over the SOC channel (automatically repeated). O-P-TRAINING-ES is identical to O-P-TRAINING. O-SIGNATURE-ES is also identical to O-SIGNATURE, except for the message code (see Table III.1).

Once the VTU-R is synchronized and has successfully decoded O-SIGNATURE-ES, the VTU-R transmits R-P-TRAINING-ES that is identical to R-P-TRAINING1. The message R-MSG1-ES is sent in parallel over the SOC channel (automatically repeated). R-MSG1-ES is identical to R-MSG1, except for the message code (see Table III.1).

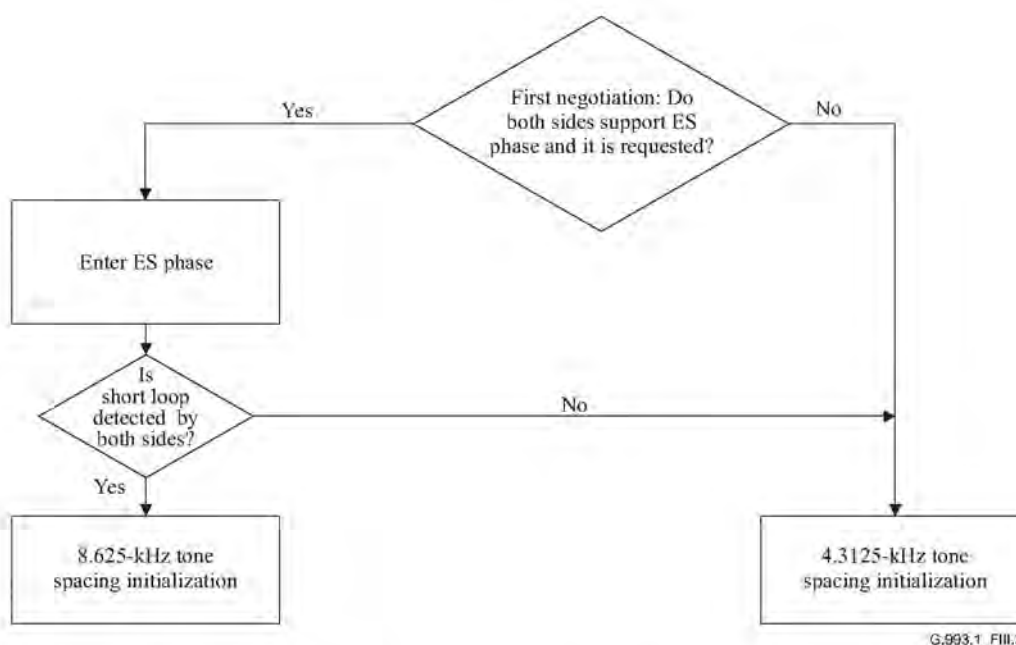
The VTU-O and VTU-R perform the short loop detection simultaneously while receiving R-MSG1-ES and O-SIGNATURE-ES, respectively. The decision to enter the 8.625-kHz tone spaced initialization may be based on the PSD level of the received signal at higher frequencies where the 8.625-kHz tone spacing would provide an advantage.

The final negotiation takes place after the completion of the short loop detection. If the measured loop length is short enough so that the use of the 8.625-kHz tone spacing is advantageous, both the VTU-O and VTU-R acknowledge each other by transmitting O-ACK-ES and R-ACK-ES, respectively. The final negotiation period is followed by the 8.625-kHz tone spaced initialization if and only if O-ACK-ES and R-ACK-ES are received by the VTU-R and VTU-O, respectively.

Depending on the final negotiation, the modem configuration can be switched from 4.3125 kHz to 8.625 kHz during the QUIET period followed by the symbol O-P-TRAINING and R-P-TRAINING1 transmitted from the VTU-O and VTU-R, respectively.

The flow chart of the overall initialization procedure for the 8.625-kHz tone spacing mode is shown in Figure III.2.





**Figure III.2/G.993.1 – Flow chart of the 8.625 kHz tone spaced initialization**

The message codes for the SOC messages sent during the ES phase are shown in Table III.1.

In an 8.625-kHz tone spaced system, the training and channel analysis detailed in 12 are the same as for the 4.3125-kHz tone spaced version, with the exception that tone indexes are calculated based on the 8.625-kHz tone spacing.

## BIBLIOGRAPHY

- [ITU-T G.995.1] ITU-T Recommendation G.995.1 (2001), *Overview of digital subscriber line (DSL) Recommendations*.
- [ATMF UTOPIA] ATM Forum Specification af-phy-0039.000 (1995), *UTOPIA Level 2, Version 1.0*.
- [ANSI] T1.424, VDSL Metallic interface.
- [ETSI] TS 101 270-1, VDSL Part 1: *Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Very high speed Digital Subscriber Line (VDSL); Part 1: Functional requirements*.







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# **EXHIBIT 19**



INTERNATIONAL TELECOMMUNICATION UNION

**ITU-T**

TELECOMMUNICATION  
STANDARDIZATION SECTOR  
OF ITU

**G.992.2**

(06/99)

**SERIES G: TRANSMISSION SYSTEMS AND MEDIA,  
DIGITAL SYSTEMS AND NETWORKS**

Digital transmission systems – Digital sections and digital  
line system – Access networks

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**Splitterless asymmetric digital subscriber line  
(ADSL) transceivers**

**ITU-T Recommendation G.992.2**

(Previously CCITT Recommendation)

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**ITU-T RECOMMENDATION G.992.2**

**SPLITTERLESS ASYMMETRIC DIGITAL SUBSCRIBER  
LINE (ADSL) TRANSCEIVERS**

**Summary**

This Recommendation describes the interface between the telecommunications network and the customer installation in terms of their interaction and electrical characteristics. This Recommendation allows the transmission of POTS and V-series data services simultaneously with a digital channel over a single mixed gauge twisted metallic pair. Annex C defines the procedures to operate in a TCM-ISDN noise environment. Operation in the frequency band over BRA-ISDN is for further study.

This Recommendation includes procedures to allow provisioning without the need for "splitters", typically installed at the ingress to the customer premises. Additionally, power management procedures and link states are specified to achieve power savings at the central office and customer premises.

**Source**

ITU-T Recommendation G.992.2 was prepared by ITU-T Study Group 15 (1997-2000) and was approved under the WTSC Resolution No. 1 procedure on 22 June 1999.

## FOREWORD

ITU (International Telecommunication Union) is the United Nations Specialized Agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of the ITU. The ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Conference (WTSC), which meets every four years, establishes the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

The approval of Recommendations by the Members of the ITU-T is covered by the procedure laid down in WTSC Resolution No. 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

## NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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As of the date of approval of this Recommendation, the ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

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**Recommendation G.992.2****SPLITTERLESS ASYMMETRIC DIGITAL SUBSCRIBER  
LINE (ADSL) TRANSCEIVERS***(Geneva, 1999)***1 Scope**

This Recommendation describes the interface between the telecommunications network and the customer installation in terms of their interaction and electrical characteristics. The requirements of the Recommendation apply only to a single asymmetric digital subscriber line (ADSL). ADSL allows the provision of voiceband services, including POTS and V-series data services, and a number of digital channels.

The transmission system is designed to operate on mixed gauge two-wire twisted metallic pairs over the existing copper facilities and over the customer premises wiring. The transmission system is based on the use of loop plant cables without loading coils. Bridged taps in the loop plant are acceptable in all but a few unusual situations.

Operation in the frequency band over ISDN is for further study.

An overview of Digital Subscriber Line Transceivers can be found in Recommendation G.995.1.

**2 References**

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; all users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

- [1] ITU-T Recommendation I.361 (1999), *B-ISDN ATM layer specification*.
- [2] ITU-T Recommendations I.432 x-series, *B-ISDN user-network interface – Physical layer specification*.
- [3] ITU-T Recommendation G.703 (1998), *Physical/electrical characteristics of hierarchical digital interfaces*.
- [4] ITU-T Recommendation G.707 (1996), *Network node interface for the synchronous digital hierarchy (SDH)*.
- [5] ITU-T Recommendation G.961 (1993), *Digital transmission system on metallic local lines for ISDN basic rate access*.
- [6] ITU-T Recommendation G.994.1 (1999), *Handshake procedures for digital subscriber line (DSL) transceivers*.
- [7] ITU-T Recommendation G.992.1 (1999), *Asymmetric digital subscriber line (ADSL) transceivers*.
- [8] ITU-T Recommendation G.996.1 (1999), *Test procedures for digital subscriber line (DSL) transceivers*.
- [9] ITU-T Recommendation G.997.1 (1999), *Physical layer management for digital subscriber line (DSL) transceivers*.

- [10] CCITT Recommendation T.35 (1991), *Procedure for the allocation of CCITT defined codes for non-standard facilities*.
- [11] ITU-T Recommendation O.41 (1994), *Psophometer for use on telephone-type circuits*.

### 3 Definitions and abbreviations

#### 3.1 Definitions

This Recommendation defines the following terms:

- 3.1.1 data frame:** A frame of bytes that compose part of the superframe.
- 3.1.2 downstream:** The transport of data in the ATU-C to ATU-R direction.
- 3.1.3 DMT symbol:** A collection of analog samples that constitute a modulated Data Frame.
- 3.1.4 mux data frame:** A data entity consisting of AS0/LS0 and the Sync Byte (SB).
- 3.1.5 AS0:** The data channel from the ATU-C to the ATU-R.
- 3.1.6 superframe:** A data entity consisting of 68 Data Frames and one Sync Frame.
- 3.1.7 LS0:** The data channel from the ATU-R to the ATU-C.
- 3.1.8 sync byte:** A byte of data in the Mux Data Frame that contains either aoc, eoc or IB bits.
- 3.1.9 sync symbol:** A DMT symbol modulated with a constant data pattern.
- 3.1.10 sync frame:** A frame of bytes that compose part of the superframe.
- 3.1.11 FEC output frame:** A frame of data presented to the constellation encoder after Reed-Solomon encoding.
- 3.1.12 upstream:** The transport of data in the ATU-R to ATU-C direction.
- 3.1.13 indicator bits:** Bits used for OAM purposes.
- 3.1.14 subcarrier:** A particular complex valued input,  $Z_i$ , to the IDFT.
- 3.1.15 splitter:** A filter that separates the high frequency signals (ADSL) from the voiceband signals (frequently called POTS splitter).
- 3.1.16 voiceband:** The frequency band from 0 to 4 kHz.
- 3.1.17 voiceband services:** POTS and all data services that use the voiceband or part of it.
- 3.1.18 network timing reference:** An 8 kHz timing marker used to support the distribution of a timing reference over the network.

#### Power Cutback definitions

- 3.1.19 absolute downstream fast retrain power cutback:** The addition of Fast Retrain Politeness Power Cutback and Relative Downstream Fast Retrain Power Cutback.
- 3.1.20 absolute upstream fast retrain power cutback:** A power cutback at the ATU-R transmitter relative to ATU-R Nominal Level. Transmitted to the ATU-C in R-MSG-FR1.
- 3.1.21 fast retrain politeness power cutback:** A power cutback relative to the Nominal Level at the ATU-C as applied to the previous C-REVERB-FR1 signal. Transmitted in C-MSG-FR1.
- 3.1.22 initialization politeness power cutback:** A power cutback at the ATU-C transmitter as a result of measurement of the average upstream loop attenuation during R-REVERB1.
- 3.1.23 nominal level:** Nominal transmit level at the ATU-R shall be  $-38$  dBm/Hz. Nominal transmit level at the ATU-C shall be  $-40$  dBm/Hz.

**3.1.24 relative downstream fast retrain power cutback:** An additional power cutback to the ATU-C transmit power that is requested by the ATU-R. This power cutback shall be relative to: (ATU-C Nominal Level – the ATU-C Fast Retrain Politeness Power Cutback). Transmitted to the ATU-C in R-MSG-FR1.

## 3.2 Abbreviations

This Recommendation uses the following abbreviations:

ADSL	Asymmetric Digital Subscriber Line
AFE	Analog Front End
AGC	Automatic Gain Control
ANSI	American National Standards Institute
aoc	ADSL Overhead Control
AS0	Downstream data channel
ATM	Asynchronous Transfer Mode
ATN	Attenuation
ATU	ADSL Transceiver Unit
ATU-C	ATU at the Central Office
ATU-R	ATU at the Remote End
BER	Bit Error Rate
C-B&G	Central Office Bits and Gains Information
CLP	Cell Loss Priority
CO	Central Office
CRC	Cyclic Redundancy Check
DAC	Digital-to-Analog Converter
dBm	Ratio (in decibels) of a power level with respect to a reference power of 1 picowatt (equivalent –90 dBm) (see Annex A/O.41)
DF	Data Frame
DMT	Discrete MultiTone
DPRD	Downstream Pseudo Random Data
EC	Echo Cancellation
eoc	Embedded Operations Channel
FDM	Frequency Division Multiplex
FEBC	Far-end Block Error
FEC	Forward Error Correction
FECC	Far-end Echo Cancellation
FFEC	Far-end Forward Error Correction
FHEC	Far-end Header Error Check
FLCD	Far-end Loss of Cell Delineation

FNCD	Far-end No Cell Delineation
FOCD	Far-end Out of Cell Delineation
GF	Galois Field
GNTPDN	Grant Power Down
GSTN	General Switched Telephone Network
HEC	Header Error Control
IB	Indicator Bit
IDFT	Inverse Discrete Fourier Transform
ISDN	Integrated Services Digital Network
K	Number of bytes in a Mux Data Frame
LCD	Loss of Cell Delineation
LOF	Loss of Frame
los	Loss of Signal
lpr	Loss of Power
LS0	Upstream data channel
LSB	Least Significant Bit
LTR	Local Timing Reference
MC	Maximum Count indication
MSB	Most Significant Bit
N	Number of bytes in an FEC Output Data Frame
NCD	No Cell Delineation
$N_{CP}$	Number of cyclic prefix values
$N_{downi}$	Size of constellation in bits for subcarrier i
$N_{FEC}$	Number of bytes in a Reed-Solomon Codeword
$N_{IDFT}$	Number of output values of the IDFT
NMS	Network Management System
$N_{SC}$	Number of subcarriers
NT	Network Termination
NTR	Network Timing Reference
$N_{updownmax}$	Maximum number of bits assigned per subcarrier
OCD	Out of Cell Delineation
OSS	Operations Support System
PDU	Protocol Data Unit
PHY	Physical
PMD/TC	Physical media dependent/transmission conversion
POTS	Plain Old Telephone Service

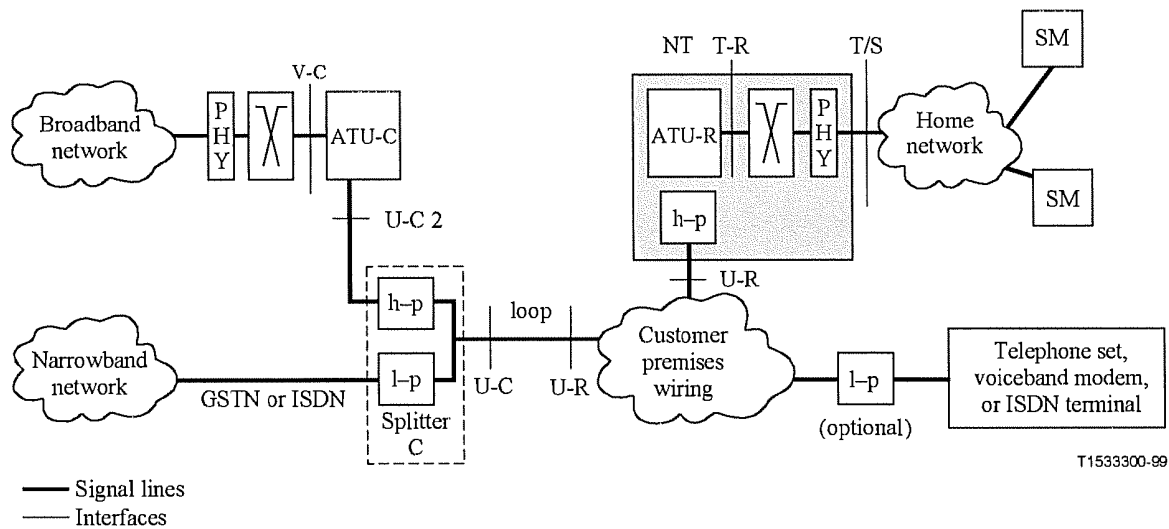
ppm	parts per million
PRD	Pseudo-random Downstream Sequence
PRU	Pseudo-random Upstream Sequence
PSD	Power Spectrum Distribution
QAM	Quadrature Amplitude Modulation
R	Number of parity bytes per Reed-Solomon codeword
R-B&G	Remote End Bits and Gains Information
RDI	Remote Defect Indication
REJPDN	Reject Power Down
REQPDN	Request Power Down
RFI	Indication Remote Failure
RRSI	A field in an C/R-RATES and C/R-RATES-RA message
RS	Reed-Solomon
Rx	Receiver
S	DMT symbols per Reed-Solomon codeword
SB	Sync Byte
SEF	Severely Errored Frame
SF	Sync Frame
SM	Service Module
SNR	Signal-to-Noise Ratio
T-R	T reference point at the remote end
Tx	Transmitter
U-C	U reference point at the CO end
UPRD	Upstream Pseudo-Random Data
UTC	Unable To Comply
V-C	V reference point at the central office



## 4 Reference models

### 4.1 System reference model

The system reference model shown in Figure 1 describes the functional blocks required to provide ADSL service.

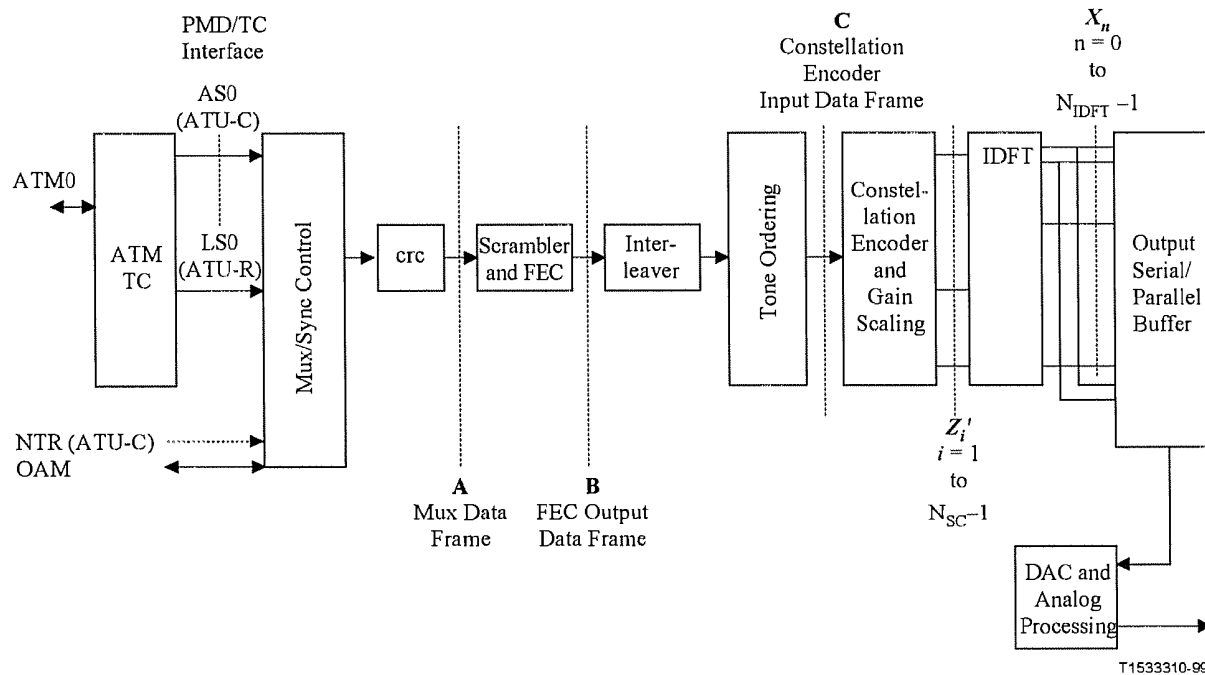


NOTE – An optional ATU-R splitter may be utilized to isolate customer premises wiring and voiceband equipment from the ADSL signal.

**Figure 1/G.992.2 – System reference model**

## 4.2 ATU reference model

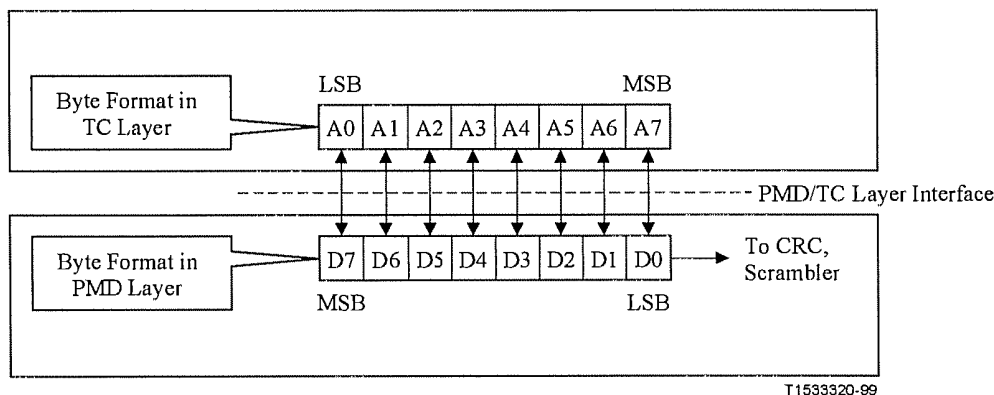
Figure 2 is a block diagram of an ADSL Transceiver Unit (ATU) transmitter showing the functional blocks and interfaces that are referenced in this Recommendation for the transport of ATM data.



**Figure 2/G.992.2 – ATU reference transmitter model**

Support of ATM is required. The following requirements shall be supported:

- Byte boundaries at the V-C and T-R interface shall be preserved in the ADSL data frame.
- Outside the AS0/LS0 serial interfaces, data bytes are transmitted MSB first in accordance with Recommendations I.361 and I.432. All serial processing in the ADSL frame (e.g. crc, scrambling, etc.) shall, however, be performed LSB first, with the outside world MSB considered by the ADSL as LSB. As a result, the first incoming bit (outside world MSB) will be the first processed bit inside the ADSL (ADSL LSB) (see Figure 3), and the CLP bit of the ATM cell header will be carried in the MSB of the ADSL frame byte (i.e. processed last).
- ADSL equipment shall support bearer channel AS0 downstream and bearer channel LS0 upstream as defined in clause 5.



- The first serial bit handed from the TC layer to the PMD layer across the PMD/TC interface is the LSB of each PMD layer byte.
- The first serial bit handed from the PMD layer to the TC layer across the PMD/TC interface is the MSB of each TC layer byte.

**Figure 3/G.992.2 – Illustration of byte flipping**

## 5 Transport capacity

The ATU shall transport a single duplex bearer channel. The bearer channel data rate shall be programmable in multiples of 32 kbit/s.

The maximum net data rate transport capacity of the ATU will depend on the characteristics of the loop on which the system is deployed, and on certain configurable options that affect overhead (see Note). The ATU bearer channel rate shall be configured during the initialization and training procedures.

The transport capacity of the ATU system is defined only as that of the bearer channel. When, however, an ADSL system is installed on a line that also carries POTS or TCM-ISDN signals, the overall capacity is that of POTS or ISDN plus ADSL.

In addition, the ATU-C may transport a Network Timing Reference (NTR). The means for doing this are specified in 7.2.

Bearer channel AS0 shall support the transport of data at all integer multiples of 32 kbit/s from 64 kbit/s to 1.536 Mbit/s. Bearer channel LS0 shall support all integer multiples of 32 kbit/s from 32 kbit/s to 512 kbit/s.

NOTE – One part of the ATU initialization and training sequence estimates the loop characteristics to determine whether the number of bytes per Discrete MultiTone (DMT) symbol required for the requested configuration's aggregate data rate can be transmitted across the given loop. The net data rate is then the aggregate data rate minus system overhead. Part of the system overhead is dependent on the configurable options.

**Table 1/G.992.2 – Data rate terminology for ATM transport**

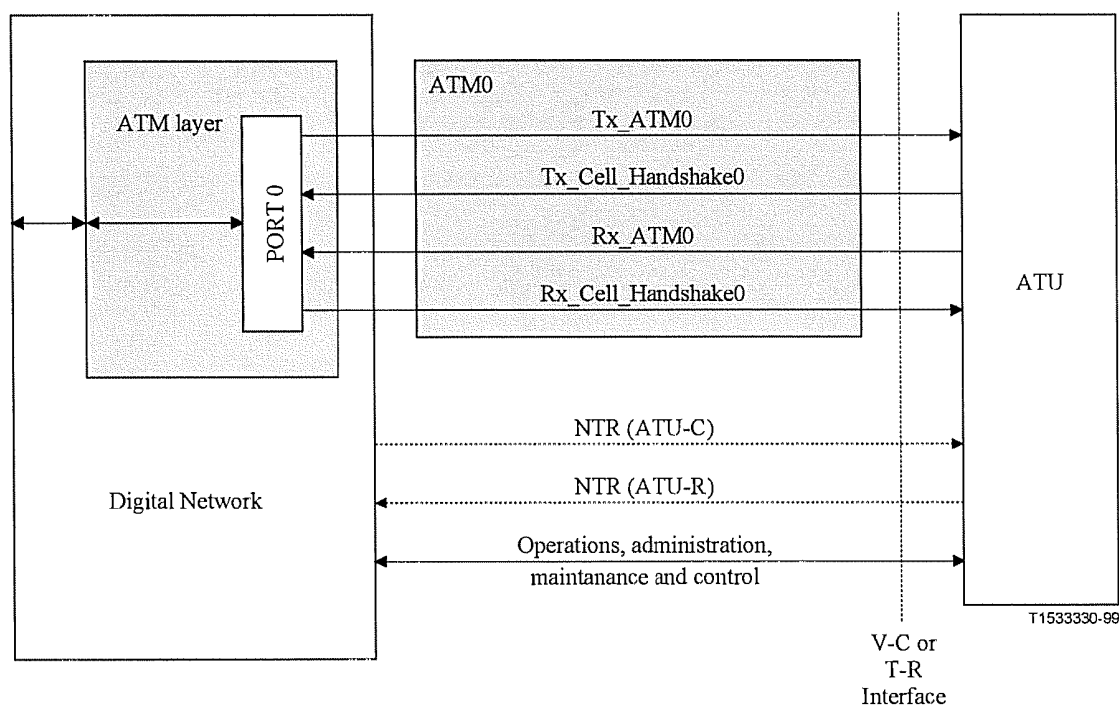
Data rate				Equation (kbit/s)	Ref. point
$53 \times 8$	$\times$	ATM cell rate	= "Net data rate"	$(B_I) \times 32$	AS0, LS0
"Net data rate"	+	Frame overhead rate	= "Aggregate data rate"	$\Sigma(K_I) \times 32$	A
"Aggregate data rate"	+	RS Coding overhead rate	= Line rate	$\Sigma(N_I) \times 32 = \Sigma b_I \times 4$	B, U

## 6 ATU interfaces

### 6.1 ATU interface for ATM transport

The functional data interfaces at the ATU for ATM are shown in Figure 4.

Flow control functionality shall be available on the interface to allow the ATU (i.e. the physical layer) to control the cell flow to and from the ATM layer. This functionality is represented by Tx\_Cell\_Handshake and Rx\_Cell\_Handshake. A cell may be transferred from the ATM to the PHY layer only after the ATU-C has activated the Tx\_Cell\_Handshake. Similarly, a cell may be transferred from the PHY layer to the ATM layer only after the Rx\_Cell\_Handshake.



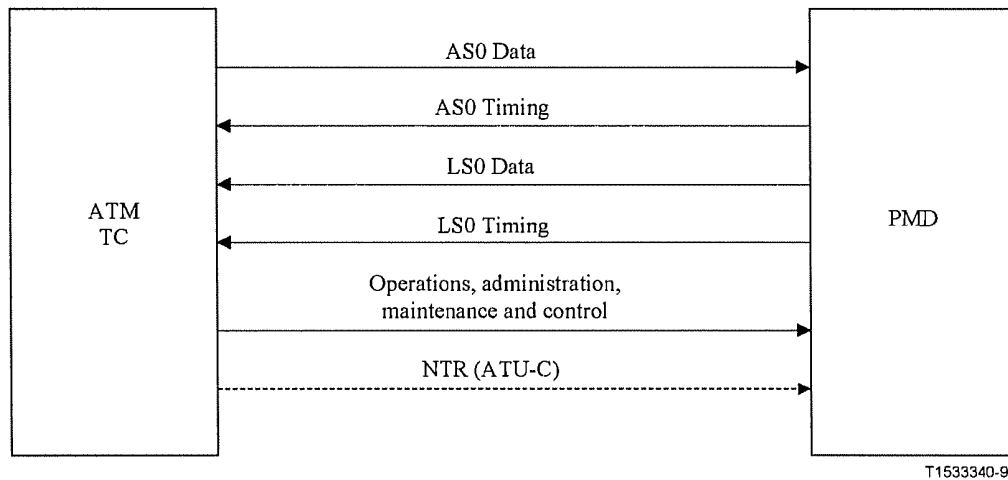
NOTE – Dashed lines indicate optional functions.

**Figure 4/G.992.2 – ATU functional interface for ATM**

### 6.2 ATU PMD to TC logical interface

The functional data interface between the PMD and ATM TC layers of the ATU are shown in Figure 5. This interface is a logical interface only and does not imply a physical implementation.

The PMD to TC logical interface is byte-oriented. The bit ordering and timing are described in 4.2 and 7.1.2.4.



**Figure 5/G.992.2 – PMD to TC logical interface**

## 7 ATM functional characteristics

### 7.1 ATM transport protocol specific functionalities

#### 7.1.1 Payload transfer delay

The one-way transfer delay (excluding cell specific functionalities) for payload bits from the V reference point at central office end (V-C) to the T reference point at remote end (T-R) should be less than or equal to  $(4 + (S - 1)/4 + (S \times D)/4)$  ms. One-way payload transfer delay shall be less than  $10 + (S \times D)/4$ . The same requirement applies in the opposite direction, from the T-R reference point to the V-C reference point.

The additional delay introduced by the ATM cell specific functionality is implementation specific.

#### 7.1.2 ATM cell specific functionality

##### 7.1.2.1 Idle cell insertion

Idle cells shall be inserted in the transmit direction for cell rate de-coupling. Idle cells are identified by the standardized pattern for the cell header given in Recommendation I.432.

Idle cells shall be discarded by an ATU receiver.

##### 7.1.2.2 Header Error Control (HEC) generation

The HEC byte shall be generated in the transmit direction as described in Recommendation I.432, including the recommended modulo 2 addition (XOR) of the pattern binary  $01010101_b$  to the HEC bits.

The generator polynomial coefficient set used and the HEC sequence generation procedure shall be in accordance with Recommendation I.432.

##### 7.1.2.3 Cell payload scrambling

Scrambling of the cell payload field shall be used in the transmit direction to improve the security and robustness of the HEC cell delineation mechanism. The self synchronizing scrambler polynomial  $x^{43} + 1$  and procedures defined in Recommendation I.432 shall be implemented.

The cell payload shall be descrambled by an ATU receiver.



#### 7.1.2.4 Bit timing and ordering

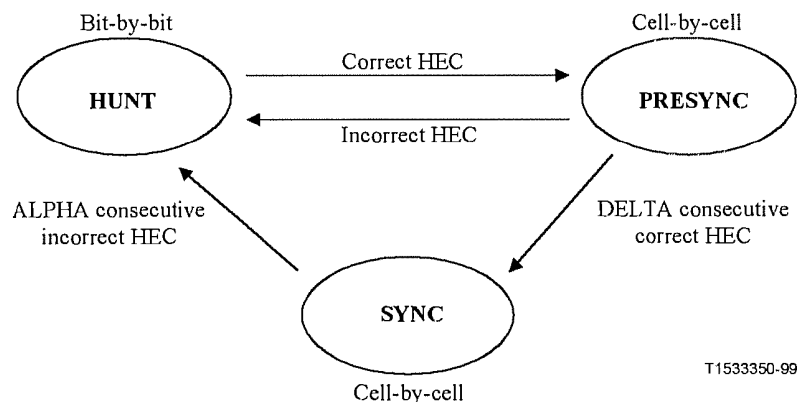
When interfacing ATM data bytes to the AS0/LS0 bearer channel, the most significant bit (MSB) shall be sent first. The AS0 and LS0 bearer channel data rates shall be integer multiples 32 kbit/s, with bit timing synchronous with the ADSL downstream modem timing base.

#### 7.1.2.5 Cell delineation

The cell delineation function permits the identification of cell boundaries in the payload. It uses the HEC field in the cell header.

Cell delineation shall be performed using a coding law checking the HEC field in the cell header according to the algorithm described in Recommendation I.432. The ATM cell delineation state machine is shown in Figure 6. The details of the state diagram are described below:

- In the HUNT state, the delineation process is performed by checking bit by bit for the correct HEC. Once such an agreement is found, it is assumed that one header has been found, and the method enters the PRESYNC state. When byte boundaries are available, the cell delineation process may be performed byte by byte.
- In the PRESYNC state, the delineation process is performed by checking cell by cell for the correct HEC. The process repeats until the correct HEC has been confirmed DELTA (see Note) times consecutively. If an incorrect HEC is found, the process returns to the HUNT state.
- In the SYNC state the cell delineation will be assumed to be lost if an incorrect HEC is obtained ALPHA times consecutively.



**Figure 6/G.992.2 – ATM cell delineation state machine**

NOTE – With reference to Recommendation I.432, no recommendation is made for the values of ALPHA and DELTA as the choice of these values is not considered to effect interoperability. However, it should be noted that the use of the values suggested in Recommendation I.432 (ALPHA = 7, DELTA = 6) may be inappropriate due to the particular transmission characteristics of ADSL.

#### 7.1.2.6 Header Error Control verification

The HEC covers the entire cell header. The code used for this function is capable of:

- either single bit error correction;
- or multiple bit error detection.

Error detection shall be implemented as defined in Recommendation I.432 with the exception that any HEC error shall be considered as a multiple bit error, and therefore, HEC error correction shall not be performed.

### 7.1.3 Framing structure for ATM transport

The ATU-C transmitter shall preserve V-C and T-R interface byte boundaries (explicitly present or implied by ATM cell boundaries) at the U-C interface.

## 7.2 Network Timing Reference

### 7.2.1 Optional NTR capability

To support the distribution of a timing reference over the network, an ATU-C may optionally transport an 8 kHz timing marker as NTR. The 8 kHz timing marker is input to the ATU-C as part of the interface at the V-C reference point.

### 7.2.2 Transport of the NTR

If included, an ATU-C shall transport the NTR as follows:

The ATU-C shall generate an 8 kHz local timing reference (LTR) by dividing its sampling clock by the appropriate integer. It shall transmit the change in phase offset between the input NTR and LTR (measured in cycles of a 1.104 MHz clock in units of approximately 905 ns) from the previous superframe to the present one. The phase offset shall be encoded into four bits ntr3-ntr0 (with ntr3 the MSB), representing a signed integer in the  $-8$  to  $+7$  range in twos-complement notation. The bits ntr3-ntr0 shall be carried in the indicator bits 23 (ntr3) to 20 (ntr0); see Table 4.

NOTE 1 – A positive value of the change of phase offset,  $\Delta^2\phi$ , shall indicate that the LTR is higher in frequency than the NTR.

NOTE 2 – The NTR has a maximum frequency variation of  $\pm 32$  ppm. The LTR, as specified in 7.2.2, has a maximum frequency variation of  $\pm 50$  ppm. The maximum mismatch is therefore  $\pm 82$  ppm. This would result in an average change of phase offset in one 17 ms superframe of approximately  $\pm 1.75$  clock cycles, which can be mapped into four overhead bits.

NOTE 3 – One method that the ATU-C may use to measure this change of phase offset is shown in Figure 7.

NOTE 4 – Alternatively, the ATU-C may choose to lock its downstream sampling clock (1.104 MHz) to 138 times the NTR frequency; in that case it shall encode  $\Delta^2\phi$  to zero.

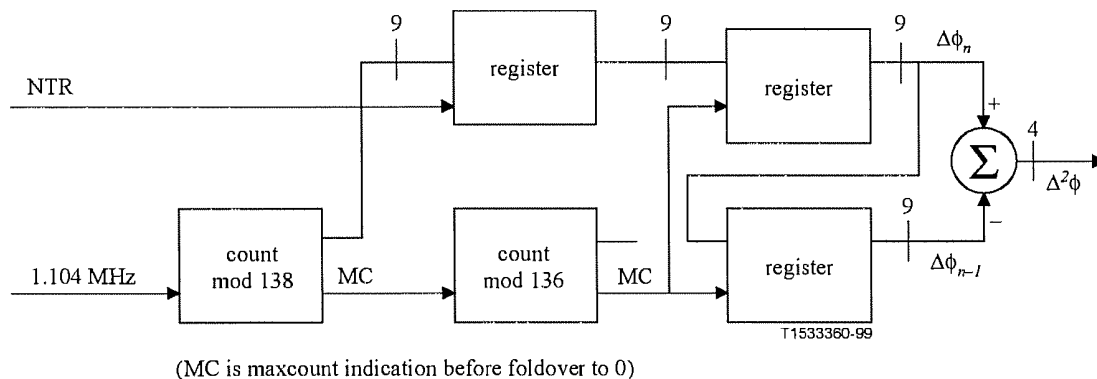


Figure 7/G.992.2 – Example implementation of the  $\Delta^2\phi$  measurement

### 7.3 Framing

#### 7.3.1 Relationship to G.992.1 framing

The framing is equivalent to the "reduced overhead mode with merged fast and sync bytes" as defined in Recommendation 7.4.4.2/G.992.1 using only the "interleave buffer" definition. Only a single duplex channel is supported, consisting of a simplex AS0 downstream channel and a simplex LS0 upstream channel.

#### 7.3.2 Bit ordering

External to the AS0/LS0 serial interfaces data bytes are transmitted MSB first in accordance with Recommendations G.703, G.709, I.361 and I.432. All serial processing in the superframe (e.g. crc, scrambling, etc.) shall, however, be performed LSB first, with the outside world MSB considered as the LSB. As a result, the first incoming bit (outside world MSB) will be the first bit processed by the ATU (ATU LSB).

#### 7.3.3 Data framing and reference points

Figure 2 shows a functional block diagram of the ATU transmitter with reference points for data framing. A cyclic redundancy check (crc), scrambling, forward error correction (FEC) coding and interleaving shall be applied to the contents of the superframe. The data stream shall then be tone ordered as defined in 7.7, and combined into a data symbol that is input to the constellation encoder. After constellation encoding the data shall be modulated to produce an analog signal for transmission across the customer loop.

DMT symbol boundaries are delineated by the cyclic prefix inserted by the modulator (see 7.11). Superframe boundaries are delineated by the Sync Symbol, which shall also be inserted by the modulator, and which carries no user data (see 7.3.3.1).

Because of the addition of FEC redundancy bytes and data interleaving, the data symbols (i.e. bit-level data prior to constellation encoding) have different structural appearance at the three reference points through the transmitter. As shown in Figure 2, the reference points for which data framing will be described in the following subclauses are:

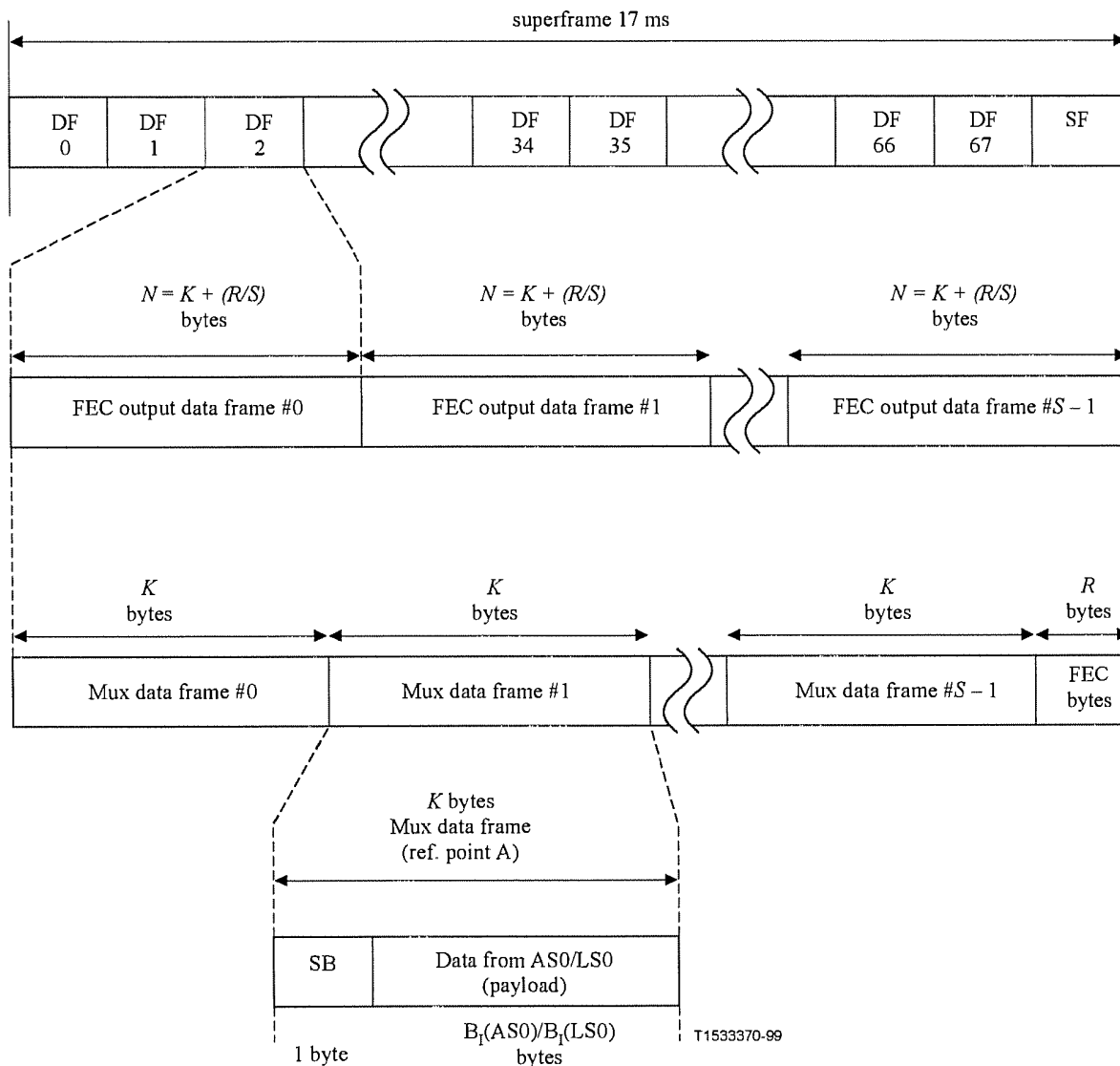
**A: Mux Data Frame:** The synchronized data after the crc has been inserted (crc is specified in 7.3.3.1.2). Mux Data Frames shall be generated at a nominal 4 kHz rate. Each Mux Data Frame shall contain  $K$  bytes.

**B: FEC Output Data Frame:** The data frame generated at the output of the FEC encoder at the DMT symbol rate, where an FEC block may span more than one DMT symbol period. Each FEC Output Data Frame shall contain  $N$  bytes [ $N = K + (R/S)$ ].

**C: Constellation Encoder Input Data Frame:** The data frame presented to the constellation encoder.

##### 7.3.3.1 Superframe structure

The superframe structure is shown in Figure 8. Each superframe is composed of 68 "Data Frames" (DF), numbered from 0 to 67, which are encoded and modulated into DMT symbols, followed by a "Sync Frame" (SF), which carries no user or overhead bit-level data and is inserted by the modulator to establish superframe boundaries. From the bit-level and user data perspective, the DMT symbol rate is 4000 (period = 250  $\mu$ s), but in order to allow for the insertion of the SF the transmitted DMT symbol rate is  $69/68 \times 4000$ .



**Figure 8/G.992.2 – Superframe structure**

#### 7.3.3.1.1 Use of Sync Byte (SB)

The crc, Indicator Bits, eoc and aoc functions shall be carried in the SB assigned to separate DFs within the superframe structure. The crc is transmitted in frame 0 and the Indicator Bits in frames 1, 34 and 35. The aoc and eoc bytes are assigned to alternate pairs of frames. The assignment of overhead functions to the SB shall be as shown in Table 2.

**Table 2/G.992.2 – Sync Byte functions**

Data Frame (DF)	Sync Byte contents
0	crc
1	IB0-7
34	IB8-15
35	IB16-23
$4n + 2, 4n + 3$ with $n = 0 \dots 16, n \neq 8$	eoc
$4n, 4n + 1$ with $n = 1 \dots 16$	aoc
NOTE – The only allowable eoc synchronization code is "no synchronization action".	

**7.3.3.1.1.1 eoc byte encoding**

The eoc bits transported in the SB shall contain either eoc bits or the hexadecimal value of XX0011X0<sub>b</sub> in downstream and 000011X0<sub>b</sub> in upstream (with X vendor discretionary) indicating "no synchronization action". The "no synchronization action" byte shall be used as fill when there is no eoc channel data to be transmitted. When transporting eoc data, the SB eoc bytes shall be encoded as in Figure 9.

Even-numbered data frames	eoc6	eoc5	eoc4	eoc3	eoc2	eoc1	r1	1 <sub>b</sub>
	MSB						LSB	
Odd-numbered data frames	eoc13	eoc12	eoc11	eoc10	eoc9	eoc8	eoc7	1 <sub>b</sub>

**Figure 9/G.992.2 – Sync Byte encoding for transport of eoc bytes**

In all frames, bit 7 is MSB and bit 0 is LSB. Bit 0 shall be set to 1<sub>b</sub> to indicate that the eoc byte contains an eoc message. Bit r1 shall be set to 1<sub>b</sub>. The use of r1 is reserved by the ITU-T.

**7.3.3.1.1.2 aoc byte encoding**

The aoc bytes transported in the SB shall contain the aoc channel data as described in clause 9. When no aoc data is available for transmission in the superframe, the aoc byte shall contain the stuffing byte defined in 9.4.

In all frames, bit 7 is MSB and bit 0 is LSB (Figure 10).

	MSB						LSB	
All data frames	aoc7	aoc6	aoc5	aoc4	aoc3	aoc2	aoc1	aoc0

**Figure 10/G.992.2 – Sync Byte encoding for transport of aoc bytes****7.3.3.1.2 Cyclic redundancy check (crc)**

Eight bits per superframe shall be used for the crc on the superframe (crc0-crc7). As shown in Table 2, the "Sync Byte" (SB) carries the crc check bits for the previous superframe in frame 0.



The crc bits are computed from the k message bits using the equation:

$$\text{crc}(D) = M(D) D^8 \text{ modulo } G(D)$$

where:

$$M(D) = m_0 D^{k-1} + m_1 D^{k-2} + \dots + m_{k-2} D + m_{k-1} \quad \text{is the message polynomial}$$

$$G(D) = D^8 + D^4 + D^3 + D^2 + 1 \quad \text{is the generating polynomial}$$

$$\text{crc}(D) = c_0 D^7 + c_1 D^6 + \dots + c_6 D + c_7 \quad \text{is the check polynomial}$$

and D is the delay operator.

That is, the crc is the remainder when  $M(D) D^8$  is divided by  $G(D)$ . Each byte shall be clocked into the crc least significant bit first. In all frames, bit 7 = MSB and bit 0 = LSB. The bits covered by the crc are listed in Table 3.

**Table 3/G.992.2 – crc coverage**

Data Frame (DF)	crc coverage
0	AS0 and LS0 bytes
1-67	Sync Byte (SB), followed by AS0 and LS0 bytes.

#### 7.3.3.1.3 Indicator Bits (IB0-IB23)

As shown in Table 2, the SB carries Indicator Bits in Data Frames 1, 34 and 35. The indicator bits are defined in Table 4.

A description of the use of the indicator bits can be found in clause 10.

**Table 4/G.992.2 – Definition of indicator bits, ATU-C transmitter**

Indicator bit (see Note 1)	Definition
IB0-IB7	Reserved by the ITU-T (see Note 1)
IB8	febe-i
IB9	fecc-i
IB10	Reserved by the ITU-T
IB11	Reserved by the ITU-T
IB12	los
IB13	RDI
IB14	ncd-i
IB15	Reserved by the ITU-T
IB16	hec-i
IB17-19	Reserved by the ITU-T
IB20-23	NTR bits (see 7.2.2 and Note 2)
NOTE 1 – Reserved bits are set to 1 <sub>b</sub> because all indicator bits are defined as active low.	
NOTE 2 – If the NTR is not transported, IB20-23 shall be set to 1 <sub>b</sub> .	

## 7.4 Scrambler

The binary data streams (LSB of each byte first) at reference point A shall be scrambled using the following algorithm:

$$d'_n = d_n \oplus d'_{n-18} \oplus d'_{n-23}$$

where  $d_n$  is the  $n$ -th input to the scrambler, and  $d'_n$  is the  $n$ -th output from the scrambler. This is illustrated in Figure 11.

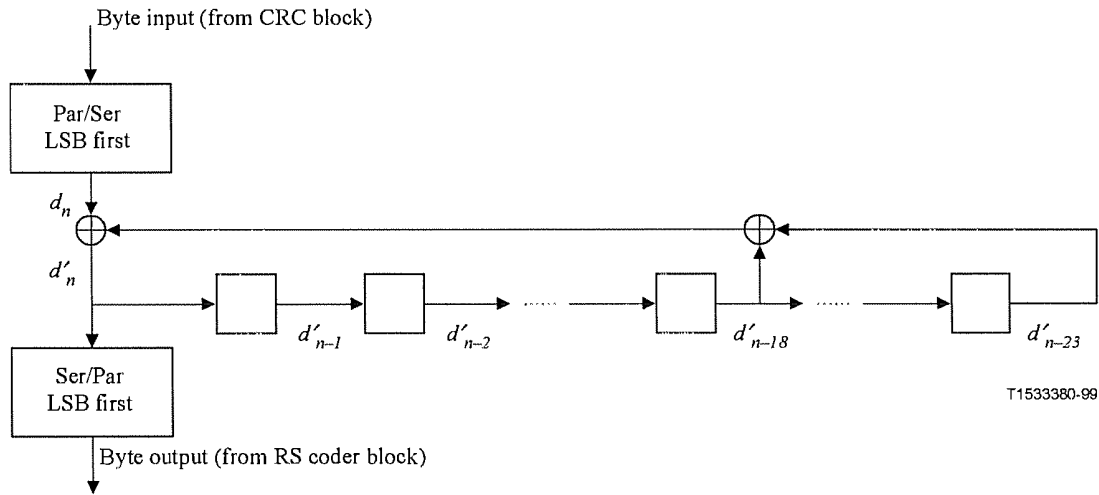


Figure 11/G.992.2 – Scrambler

## 7.5 Reed-Solomon Forward Error Correction

$R/S$  bytes shall be added to the Mux Data Frame (reference point A) after scrambling to produce the FEC Output Data Frame (reference point B), where  $R$  is given in the C/R-RATES1, C/R-RATES-RA and C/R-MSG-FR2 options used during initialization and Fast Retrain.

The Reed-Solomon coder shall take in  $S$  Mux Data Frames and append  $R$  Reed-Solomon FEC redundancy bytes to produce the Reed-Solomon codeword of length  $N_{\text{FEC}} = S \times K + R$  bytes. The FEC Output Data Frames shall contain  $K + (R/S)$  bytes.  $(R/S)$  shall be an integer. When  $S > 1$ , then for the  $S$  frames in a Reed-Solomon codeword, the FEC Output Data Frame (reference point B) shall partially overlap two Mux Data Frames for all except the last frame, which shall contain the last Mux Data Frame and  $R$  FEC redundancy bytes.

The ATU shall support transmission and reception with at least any combination of the Reed-Solomon FEC coding capabilities shown in Table 5.

**Table 5/G.992.2 – Minimum FEC coding capabilities for ATU**

Parameter	Capabilities
Parity bytes per $R$ - $S$ codeword	Mandatory: $R = 0, 4, 8$ Optional: $R = 16$ (see Note)
DMT symbols per $R$ - $S$ codeword	Mandatory: $S = 1, 2, 4$ and $8$ Optional: $S = 16$
Interleave depth	Mandatory: $D = 1, 2, 4, 8$ and $16$ (downstream) $D = 1, 2, 4, 8$ (upstream)
NOTE – $R$ shall be an integer multiple of $S$ .	

### 7.5.1 Reed-Solomon coding

When  $R = 0$ , no check bytes are appended and the FEC Output Data Frames are equivalent to the Mux Data Frames. For all other values of  $R$ , the following encoding procedures shall be used.

$R$  redundant check bytes  $c_0, c_1, \dots, c_{R-2}, c_{R-1}$  shall be appended to  $(K \times S)$  message bytes  $m_0, m_1, \dots, m_{K \times S-2}, m_{K \times S-1}$  to form a Reed-Solomon codeword of size  $N_{\text{FEC}} = S \times K + R$  bytes. The check bytes are computed from the message byte using the equation:

$$C(D) = M(D) D^R \text{ modulo } G(D)$$

where:

$$M(D) = m_0 D^{S \times K-1} + m_1 D^{S \times K-2} \dots + m_{S \times K-2} D + m_{S \times K-1}$$

is the message polynomial,

$$C(D) = c_0 D^{R-1} + c_1 D^{R-2} + \dots + c_{R-2} D + c_{R-1}$$

is the check polynomial, and

$$G(D) = \prod (D + \alpha^i)$$

is the generator polynomial of the Reed-Solomon code, where the index of the product runs from  $i = 0$  to  $R-1$ . That is,  $C(D)$  is the remainder obtained from dividing  $M(D) D^R$  by  $G(D)$ . The arithmetic is performed in the Galois Field  $\text{GF}(256)$ , where  $\alpha$  is a primitive element that satisfies the primitive binary polynomial  $x^8 + x^4 + x^3 + x^2 + 1$ . A data byte  $(d_7, d_6, \dots, d_1, d_0)$  is identified with the Galois Field element  $d_7 \alpha^7 + d_6 \alpha^6 \dots + d_1 \alpha + d_0$ .

### 7.5.2 Reed-Solomon Forward Error Correction superframe synchronization

After completion of Initialization and Fast Retrain, the ATU shall align the first byte of the first Reed-Solomon codeword with the first data byte of DF 0.

## 7.6 Interleaver

The Reed-Solomon codewords shall be convolutionally interleaved. The interleaving depth shall always be a power of 2. Convolutional interleaving is defined by the rule:

Each of the  $N_{\text{FEC}}$  bytes  $B_0, B_1, \dots, B_{N-1}$  in a Reed-Solomon codeword is delayed by an amount that varies linearly with the byte index. More precisely, byte  $B_i$  (with index  $i$ ) is delayed by  $(D - 1) \times i$  bytes, where  $D$  is the interleave depth.

An example for  $N_{\text{FEC}} = 5$ ,  $D = 2$  is shown in Table 6, where  $B_i^j$  denotes the  $i$ -th byte of the  $j$ -th codeword.

**Table 6/G.992.2 – Convolutional interleaving example for  $N_{\text{FEC}} = 5, D = 2$** 

<b>Interleaver input</b>	$B^j_0$	$B^j_1$	$B^j_2$	$B^j_3$	$B^j_4$	$B^{j+1}_0$	$B^{j+1}_1$	$B^{j+1}_2$	$B^{j+1}_3$	$B^{j+1}_4$
<b>Interleaver output</b>	$B^j_0$	$B^{j+1}_3$	$B^j_1$	$B^{j+1}_4$	$B^j_2$	$B^{j+1}_0$	$B^j_3$	$B^{j+1}_1$	$B^j_4$	$B^{j+1}_2$

With the above-defined rule, and the chosen interleaving depths (powers of 2), the output bytes from the interleaver always occupy distinct time slots when  $N_{\text{FEC}}$  is odd. When  $N_{\text{FEC}}$  is even, a dummy byte shall be added at the beginning of the codeword at the input to the interleaver. The resultant odd-length codeword is then convolutionally interleaved, and the dummy byte shall then be removed from the output of the interleaver.

## 7.7 Tone ordering

The bit table  $b'_i$  shall be calculated based upon the original bit table  $b_i$  as follows:

There is no ordering for the number of bits allocated to the subcarriers. Therefore, the first bit is assigned to the lowest frequency used subcarriers and the last bit is assigned to the highest frequency used subcarriers (i.e.  $b_i = b'_i$ ).

## 7.8 Constellation encoder

An algorithmic constellation encoder shall be used to construct constellations with a maximum number of bits equal to  $N_{\text{updownmax}}$ , where  $8 \leq N_{\text{updownmax}} \leq 15$ .

### 7.8.1 Bit extraction

Data bits from the DMT symbol buffer shall be extracted according to a re-ordered bit allocation table  $b'_i$ , least significant bit first. The number of bits per tone,  $b'_i$ , can take any non-negative integer values not exceeding  $N_{\text{updownmax}}$  with the exception of  $b'_i = 1$ . For a given tone  $b'_i = b$  bits are extracted from the DMT symbol buffer, and these bits form a binary word  $\{v_{b-1}, v_{b-2}, \dots, v_1, v_0\}$ . The first bit extracted shall be  $v_0$ , the LSB.

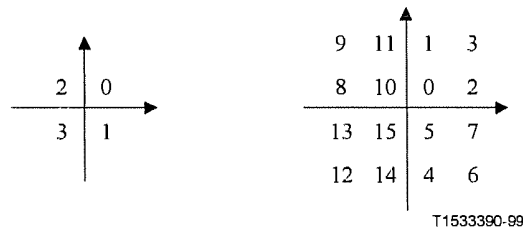
### 7.8.2 Constellation encoder

For a given sub-channel, the encoder shall select an odd-integer point (X,Y) from the square-grid constellation based on the  $b$  bits  $\{v_{b-1}, v_{b-2}, \dots, v_1, v_0\}$ . For convenience of description, these  $b$  bits are identified with an integer label whose binary representation is  $(v_{b-1}, v_{b-2}, \dots, v_1, v_0)$ . For example, for  $b = 2$ , the four constellation points are labelled 0, 1, 2, 3 corresponding to  $(v_1, v_0) = (0,0), (0,1), (1,0), (1,1)$ , respectively.

NOTE –  $v_0$  is the first bit extracted from the buffer.

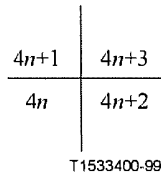
#### 7.8.2.1 Even values of $b$

For even values of  $b$ , the integer values X and Y of the constellation point (X,Y) shall be determined from the  $b$  bits  $\{v_{b-1}, v_{b-2}, \dots, v_1, v_0\}$  as follows. X and Y are the odd integers with twos-complement binary representations  $(v_{b-1}, v_{b-3}, \dots, v_1, 1)$  and  $(v_{b-2}, v_{b-4}, \dots, v_0, 1)$ , respectively. The most significant bits (MSBs),  $v_{b-1}$  and  $v_{b-2}$ , are the sign bits for X and Y, respectively. Figure 12 shows example constellations for  $b = 2$  and  $b = 4$ .



**Figure 12/G.992.2 – Constellation labels for  $b = 2$  and  $b = 4$**

The 4-bit constellation can be obtained from the 2-bit constellation by replacing each label  $n$  by a  $2 \times 2$  block of labels as shown in Figure 13.

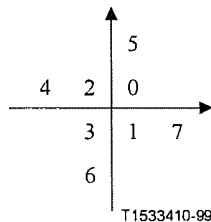


**Figure 13/G.992.2 – Expansion of point  $n$  into the next larger square constellation**

The same procedure can be used to construct the larger even-bit constellations recursively. The constellations obtained for even values of  $b$  are square in shape.

#### 7.8.2.2 Odd values of $b$ , $b = 3$

Figure 14 shows the constellation for the case  $b = 3$ .



**Figure 14/G.992.2 – Constellation labels for  $b = 3$**

#### 7.8.2.3 Odd values of $b$ , $b > 3$

If  $b$  is odd and greater than three, the two MSBs of  $X$  and the 2 MSBs of  $Y$  are determined by the five MSBs of the  $b$  bits. Let  $c = (b + 1)/2$ , then  $X$  and  $Y$  have the twos-complement binary representations  $(X_c, X_{C-1}, v_{b-4}, v_{b-6}, \dots, v_3, v_1, 1)$  and  $(Y_c, Y_{C-1}, v_{b-5}, v_{b-7}, v_{b-9}, \dots, v_2, v_0, 1)$ , where  $X_c$  and  $Y_c$  are the sign bits of  $X$  and  $Y$  respectively. The relationship between  $X_c, X_{C-1}, Y_c, Y_{C-1}$  and  $v_{b-1}, v_{b-2}, \dots, v_{b-5}$  is shown in Table 7.



**Table 7/G.992.2 – Determining the top 2 bits of  $X$  and  $Y$** 

$v_{b-1}, v_{b-2}, \dots, v_{b-5}$	$X_c, X_{C-1}$	$Y_c, Y_{C-1}$
00000 <sub>b</sub>	00 <sub>b</sub>	00 <sub>b</sub>
00001 <sub>b</sub>	00 <sub>b</sub>	00 <sub>b</sub>
00010 <sub>b</sub>	00 <sub>b</sub>	00 <sub>b</sub>
00011 <sub>b</sub>	00 <sub>b</sub>	00 <sub>b</sub>
00100 <sub>b</sub>	00 <sub>b</sub>	11 <sub>b</sub>
00101 <sub>b</sub>	00 <sub>b</sub>	11 <sub>b</sub>
00110 <sub>b</sub>	00 <sub>b</sub>	11 <sub>b</sub>
00111 <sub>b</sub>	00 <sub>b</sub>	11 <sub>b</sub>
01000 <sub>b</sub>	11 <sub>b</sub>	00 <sub>b</sub>
01001 <sub>b</sub>	11 <sub>b</sub>	00 <sub>b</sub>
01010 <sub>b</sub>	11 <sub>b</sub>	00 <sub>b</sub>
01011 <sub>b</sub>	11 <sub>b</sub>	00 <sub>b</sub>
01100 <sub>b</sub>	11 <sub>b</sub>	11 <sub>b</sub>
01101 <sub>b</sub>	11 <sub>b</sub>	11 <sub>b</sub>
01110 <sub>b</sub>	11 <sub>b</sub>	11 <sub>b</sub>
01111 <sub>b</sub>	11 <sub>b</sub>	11 <sub>b</sub>
10000 <sub>b</sub>	01 <sub>b</sub>	00 <sub>b</sub>
10001 <sub>b</sub>	01 <sub>b</sub>	00 <sub>b</sub>
10010 <sub>b</sub>	10 <sub>b</sub>	00 <sub>b</sub>
10011 <sub>b</sub>	10 <sub>b</sub>	00 <sub>b</sub>
10100 <sub>b</sub>	00 <sub>b</sub>	01 <sub>b</sub>
10101 <sub>b</sub>	00 <sub>b</sub>	10 <sub>b</sub>
10110 <sub>b</sub>	00 <sub>b</sub>	01 <sub>b</sub>
10111 <sub>b</sub>	00 <sub>b</sub>	10 <sub>b</sub>
11000 <sub>b</sub>	11 <sub>b</sub>	01 <sub>b</sub>
11001 <sub>b</sub>	11 <sub>b</sub>	10 <sub>b</sub>
11010 <sub>b</sub>	11 <sub>b</sub>	01 <sub>b</sub>
11011 <sub>b</sub>	11 <sub>b</sub>	10 <sub>b</sub>
11100 <sub>b</sub>	01 <sub>b</sub>	11 <sub>b</sub>
11101 <sub>b</sub>	01 <sub>b</sub>	11 <sub>b</sub>
11110 <sub>b</sub>	10 <sub>b</sub>	11 <sub>b</sub>
11111 <sub>b</sub>	10 <sub>b</sub>	11 <sub>b</sub>

Figure 15 shows the constellation for the case  $b = 5$ .

24	26	20	22		
19	09	11	01	03	17
18	08	10	00	02	16
31	13	15	05	07	29
30	12	14	04	06	28
25	27	21	23		

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**Figure 15/G.992.2 – Constellation labels for  $b = 5$**

The 7-bit constellation shall be obtained from the 5-bit constellation by replacing each label  $n$  by the  $2 \times 2$  block of labels as shown in Figure 13.

Again, the same procedure shall be used to construct the larger odd-bit constellations recursively.

### 7.9 Gain scaling

For the transmission of ATU data symbols, a gain scaling,  $g_i$ , shall be applied to all tones as requested by the ATU receiver during initialization and possibly updated during SHOWTIME via the bit swap procedure. Only values of  $g_i$  within a range of approximately 0.19 to 1.33 (i.e. from  $-14.5$  dB to  $+2.5$  dB) may be used. For the transmission of synchronization symbols, gain scaling shall be applied as defined in Annexes A, B and C.

The  $g_i$  values are constrained by additional limits defined in Annexes A and B.

Each point,  $(X_i, Y_i)$ , or complex number,  $Z_i = X_i + jY_i$ , output from the encoder is multiplied by  $g_i$ :  $Z'_i = g_i Z_i$ .

### 7.10 Modulation

Modulation shall use the maximum number of subcarriers  $N_{SC}$ . Table 8 defines parameters for the upstream and downstream modulation referenced in the modulation sub-paragraphs.

The actual number of subcarriers employed to modulate data may be less than the maximum and is determined during the initialization sequence. The transmitter shall designate a subset of the maximum subcarriers available for a connection during the C-REVERB1 or R-REVERB1 signals. The receiver shall designate a further subset of the transmitted subcarriers used for data modulation during the C-B&G and R-B&G signals.

ATU-R receivers shall be capable to receive the maximum set of subcarriers  $N_{SC-DN}$ .

**Table 8/G.992.2 – Parameters for upstream and downstream modulation**

Symbol	Description	Upstream	Downstream
$N_{SC}$	Number of subcarriers	$N_{SC-UP} = 32$	$N_{SC-DN} = 128$
$N_{IDFT}$	Number of output values of the IDFT ( $= 2 \times N_{SC}$ )	$N_{IDFT-UP} = 64$	$N_{IDFT-DN} = 256$
$N_{CP}$	Number of cyclic prefix values ( $= N_{SC}/8$ )	$N_{CP-UP} = 4$	$N_{CP-DN} = 16$

### 7.10.1 Subcarriers

The frequency spacing,  $\Delta f$ , between subcarriers is 4.3125 kHz, with a tolerance of  $\pm 50$  ppm. The subcarriers at frequencies  $f = n\Delta f$  are numbered  $n = 1, 2 \dots N_{sc}$ .

#### 7.10.1.1 Data subcarriers

The initialization signals defined in clause 11 allow for a maximum of  $N_{sc} - 1$  subcarriers, from  $n = 1$  to  $N_{sc} - 1$ .

The maximum number of data subcarriers may be reduced. The lower limit of  $n$  depends upon the presence of an optional POTS splitter, PSD masks, implementation specific filters and service options. In any case, the range of useable  $n$  is determined during channel analysis.

#### 7.10.1.2 Downstream Pilot subcarrier

In the downstream direction, subcarrier  $n = 64$  ( $f = 64 \times \Delta f$  kHz) shall be reserved for a pilot; that is  $b(64) = 0$  and  $g(64) = g_{sync}$ . The pilot is transmitted from the ATU-C. The value  $g_{sync}$  represents the gain scaling applied to the sync symbol as defined in Annexes A, B and C.

The data modulated onto the pilot subcarrier shall be a constant  $\{0,0\}$  generating the  $\{+,+\}$  constellation point. Use of this pilot allows resolution of sample timing in a receiver modulo-4 modulator output values. Therefore a gross timing error that is an integer multiple of four modulator output values could still persist after a micro-interruption (e.g. a temporary short-circuit, open circuit or severe line hit); correction of such timing errors is made possible by the use of the synchronization symbol defined in 7.10.3.

#### 7.10.1.3 Nyquist frequency subcarrier

The Nyquist frequency subcarrier  $n = N_{sc}$  shall not be used for data. Uses other than data are for further study.

#### 7.10.1.4 DC component

The DC component ( $n = 0$ ) shall not be used and shall contain no energy.

### 7.10.2 Modulation by the inverse discrete Fourier transform (IDFT)

The modulating transform defines the relationship between the  $N_{IDFT}$  real values  $x_n$  and the values  $Z_i$ .

The encoder and gain scaling generate only  $N_{sc} - 1$  complex values of  $Z'_i$ . These input values shall be augmented so that the vector  $Z''_i$  has Hermitian symmetry in order to generate real values of  $x_n$ . That is:

$$Z''_0 = 0 \text{ (the DC component)}$$

$$Z''_i = Z'_i \text{ for } i = 1 \text{ to } N_{sc} - 1$$

$$Z''_{N_{sc}} = \text{the Nyquist frequency subcarrier which is for further study, and}$$

$$Z''_i = \text{conj}(Z'_{N_{IDFT}-i}) \text{ for } i = N_{sc} + 1 \text{ to } N_{IDFT} - 1$$

The real valued output sequence  $x_n$  of the modulator is generated using the IDFT transform:

$$x_n = \sum_{i=0}^{N_{IDFT}-1} \exp(j\pi K_i / N_{sc}) Z''_i$$

### 7.10.3 Synchronization symbol

The synchronization symbol permits recovery of the frame boundary after micro-interruptions that might otherwise force retraining. A synchronization symbol shall be inserted after every 68 data symbols. The synchronization symbol shall be constructed using a data pattern  $d_n$ ,  $n = 1$  to  $2 \times N_{sc}$  with the following encoding method.

The first pair of bits ( $d_1$  and  $d_2$ ) shall be used for the dc component ( $i = 0$ ) and the Nyquist frequency subcarrier ( $i = N_{sc}$ ) (the power assigned to them is, of course, zero, so the bits are effectively ignored); the first and second bits of subsequent pairs are then used to define the  $X_i$  and  $Y_i$  for  $i = 1$  to  $N_{sc} - 1$  as shown in Table 9. No gain scaling shall be applied.

**Table 9/G.992.2 – Mapping of two data bits into a 4-QAM constellation**

$d_{2i+1}, d_{2i+2}$	Decimal label (see Note)	$X_i, Y_i$
$0_b, 0_b$	0	++
$0_b, 1_b$	1	+–
$1_b, 1_b$	3	--
$1_b, 0_b$	2	–+
NOTE – This is different from the mapping in Figure 12, since $d_{2i+1}$ is the first and least significant bit.		

The minimum set of subcarriers to be used is the set used for data transmission (i.e. those for which  $b_i > 0$ ); subcarriers for which  $b_i = 0$  may be used at a reduced PSD as defined in A.2.2.3 and B.2.2.3. The data modulated onto each subcarrier shall be as defined above; it shall not depend on which subcarriers are used.

### 7.10.4 Upstream data pattern

The data pattern used in the upstream synchronization symbol shall be the pseudo-random sequence UPRD  $d_n$ , for  $n = 1$  to  $2 \times N_{SC-UP}$ , defined by:

$$d_n = 1 \quad \text{for } n = 1 \text{ to } 6$$

$$d_n = d_{n-5} \oplus d_{n-6} \quad \text{for } n = 7 \text{ to } 2 \times N_{SC-UP}$$

The bits  $d_1$ – $d_6$  are re-initialized for each symbol, so each symbol uses the same data.

### 7.10.5 Downstream data pattern

The data pattern used in the downstream synchronization symbol shall be the pseudo-random sequence DPRD  $d_n$ , for  $n = 1$  to  $2 \times N_{SC-DN}$ , defined by:

$$d_n = 1 \quad \text{for } n = 1 \text{ to } 9$$

$$d_n = d_{n-4} \oplus d_{n-9} \quad \text{for } n = 10 \text{ to } 2 \times N_{SC-DN}$$

The bits  $d_1$ – $d_9$  are re-initialized for each symbol, so each symbol uses the same data.

In the downstream direction, bits 129 and 130, which modulate the pilot carrier, shall be overwritten by {0,0} generating the {+,+} constellation.

### 7.11 Cyclic prefix

The last  $N_{CP}$  samples of the output of the IDFT  $x_n$ , for  $n = (N_{IDFT} - N_{CP}$  to  $N_{IDFT} - 1)$  shall be prepended to the block of  $N_{IDFT}$  samples and read out to the digital-to-analog converter (DAC) in sequence. That is, the subscripts,  $n$ , of the DAC samples in sequence are as shown in Table 10.

**Table 10/G.992.2 – Output sample order to DAC**

	Output sample to DAC	
Cyclic prefix samples	$N_{IDFT} - N_{CP}$	← First sample transmitted
	...	
	$N_{IDFT} - 1$	
Modulator output samples	0	
	1	
	2	
	...	
	$N_{IDFT} - 1$	← Last sample transmitted

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The cyclic prefix shall be used for data and synchronization symbols beginning with the C-RATES1 and R-REVERB3 segment of the initialization sequence, as defined in clause 11.

### 7.12 Transmitter dynamic range

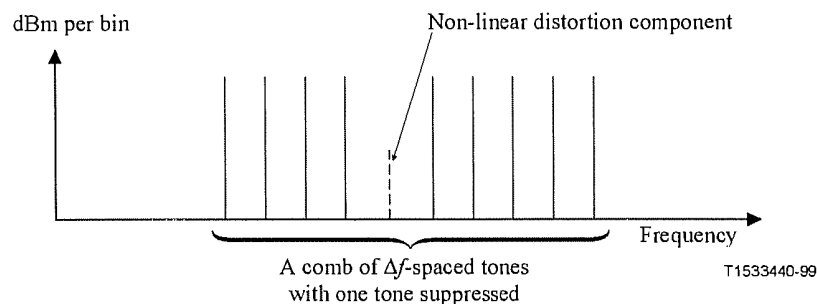
The transmitter includes all analog transmitter functions: The DAC, the anti-aliasing filter, the hybrid circuitry, and the POTS splitter. The transmitted signal shall conform to the frequency requirements as described in 7.10.1 for frequency spacing.

#### 7.12.1 Maximum clipping rate

The maximum output signal of the transmitter shall be such that the output signal shall be clipped no more than 0.00001% of the time.

#### 7.12.2 Noise/Distortion floor

The signal-to-noise plus distortion ratio of the transmitted signal in a given subcarrier is specified as the ratio of the rms value of the tone in that subcarrier to the rms sum of all the non-tone signals in the 4.3125 kHz frequency band centered on the subcarrier frequency. This ratio is measured for each subcarrier used for transmission using a MultiTone Power Ratio (MTPR) test as shown in Figure 16.



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**Figure 16/G.992.2 – MTPR test**



Over the transmission frequency band, the MTPR of the transmitter in any subcarrier shall be no less than  $(3N_{\text{down}i} + 20)$  dB, where  $N_{\text{down}i}$  is defined as the size of the constellation (in bits) to be used on subcarrier  $i$ . The minimum transmitter MTPR shall be at least 38 dB (corresponding to an  $N_{\text{down}i}$  of 6) for any subcarrier.

NOTE – Signals transmitted during normal initialization and data transmission cannot be used for this test because the DMT symbols have a cyclic prefix appended, and the PSD of a non-repetitive signal does not have nulls at any subcarrier frequencies. A gated FFT-based analyser could be used, but this would measure both the non-linear distortion and the linear distortion introduced by the transmit filter. Therefore this test will require that the transmitter be programmed with special software – probably to be used during development only. The subject of an MTPR test that can be applied to a production modem is for further study.

### 7.12.3 Transmitter spectral masks

Spectral masks for the two service options are defined in Annexes A and B. For Non-Overlapped Spectrum operation, see Annex A. For Overlapped Spectrum operation, see Annex B.

NOTE – The band from 25 to 552 kHz that is referred to is the widest possible band (used for ADSL over POTS implemented with echo cancelling). Limits defined within this band apply also to any narrower bands used.

## 8 Embedded Operations Channel (eoc)

### 8.1 eoc introduction

An embedded operations channel for communication between the ATU-C and ATU-R shall be supported for in-service and out-of-service maintenance and for the retrieval of ATU-R status information and performance monitoring parameters.

This subclause defines the messages and protocols of the eoc channel. In addition, this subclause describes the "clear eoc channel". The encoding of these messages is defined in 8.2. The insertion of eoc messages into the superframe structure is defined in 7.3.3.1.1.1.

#### 8.1.1 eoc messages overview

The eoc messages are organized into four basic types:

- 1) Bidirectional eoc messages are sent by the ATU-C and require the use of the eoc command protocol.
- 2) ATU-C to ATU-R messages are sent by the ATU-C as part of the eoc read protocol.
- 3) ATU-R to ATU-C messages are sent by the ATU-R as eoc command protocol responses or autonomous messages.
- 4) Clear eoc messages: These messages are transmitted as autonomous messages and may be sent by either the ATU-C or ATU-R.

#### 8.1.2 eoc protocol overview

eoc protocol actions are dependent upon which state the protocol is in. Figures 18 and 19 (in 8.4.2) illustrate the various eoc protocol states for both the ATU-C and ATU-R.

The eoc protocol allows the ATU-C (acting as master) to invoke eoc commands and the ATU-R (acting as slave) to respond to the commands. As the master, the ATU-C determines the rate of eoc commands over the link.

The eoc channel may also transmit autonomous messages in both the upstream and downstream direction. Using autonomous messages, the ATU-R can signal the ATU-C of events and initiate certain eoc commands. In addition, autonomous messages allow the ATU-C and ATU-R to exchange the clear eoc channel information.

During periods of no eoc activity, the eoc channel may be filled with either a HOLD or RTN eoc message as described in 8.3 or by a "no synchronization action" as described in 7.3.3.1.1.1.

If the ATU-R receives an eoc command that it cannot comply with, the ATU-R shall reply with a "Unable to Comply" message as described in 8.3.

## 8.2 eoc message encoding

The 13 bits of an eoc message are partitioned into five fields, which are summarized in Table 11.

**Table 11/G.992.2 – eoc message fields**

Field #	Bit(s)	Field	Notes
1	1, 2	ADDRESS field	Can address four locations
2	3	DATA (0 <sub>b</sub> ) or OPCODE (1 <sub>b</sub> ) field	
3	4	BYTE PARITY field Odd (binary 1) or even (0 <sub>b</sub> )	Byte order indication for multi-byte transmission
4	5	AUTONOMOUS MESSAGE field ATU-C: Set to 1 <sub>b</sub> for ATU-C commands sent to ATU-R, set to 0 <sub>b</sub> for autonomous transfers. ATU-R: Set to 1 <sub>b</sub> for response to ATU-C command, set to 0 <sub>b</sub> for autonomous transfers.	
5	6-13	INFORMATION field	See Table 13

### 8.2.1 ADDRESS field (# 1)

The two bits of the ADDRESS field can address up to four locations. Only two locations are presently defined (Table 12).

**Table 12/G.992.2 – ADDRESS field encoding**

Address bit (1, 2)	Location
00 <sub>b</sub>	ATU-R
01 <sub>b</sub>	Reserved by ITU-T
10 <sub>b</sub>	Reserved by ITU-T
11 <sub>b</sub>	ATU-C

The ATU-C shall address messages to the ATU-R by setting the ADDRESS field equal to the ATU-R address. When responding to an eoc message from the ATU-C, the ATU-R shall keep the ADDRESS field equal to its own ATU-R address. Only when sending an autonomous message to the ATU-C shall the ATU-R set the ADDRESS field equal to the ATU-C address.

### 8.2.2 DATA or OPCODE field (# 2)

A 0<sub>b</sub> in this field indicates that the INFORMATION field of the current eoc message contains a data byte; a 1<sub>b</sub> indicates that it contains an operation code for an eoc message. See Table 13.

**Table 13/G.992.2 – INFORMATION field functions**

<b>DATA (Bit 3)</b>	<b>AUTONOMOUS MESSAGE (Bit 5)</b>	<b>Function of INFORMATION field</b>
0 <sub>b</sub>	0 <sub>b</sub>	Data carries a clear eoc data octet.
0 <sub>b</sub>	1 <sub>b</sub>	Data used for read or write.
1 <sub>b</sub>	0 <sub>b</sub>	Data carries an autonomous message opcode. See Table 11.
1 <sub>b</sub>	1 <sub>b</sub>	Data carries an eoc command opcode. See Table 11.

**8.2.3 BYTE PARITY field (# 3)**

When using the Next Byte opcode to read or write the first data byte of an eoc register, this bit shall be set to 1<sub>b</sub> to indicate "odd" byte. For the next byte, it shall be set to 0<sub>b</sub> to indicate "even" byte and so on, alternately.

The BYTE PARITY field shall always be set to 1<sub>b</sub> if the eoc message is an autonomous message or if the information field carries an opcode different from the Next Byte opcode. The BYTE PARITY field may be set to 0<sub>b</sub> otherwise.

**8.2.4 AUTONOMOUS MESSAGE field (# 4)**

The ATU-C sets this field to a 1<sub>b</sub> to indicate that the current eoc message is an eoc protocol command (master) message, and sets it to a 0<sub>b</sub> to indicate that the eoc message is an autonomous message. The ATU-R sets this field to a 1<sub>b</sub> to indicate that the current eoc message is an eoc protocol response (slave) message, and sets it to a 0<sub>b</sub> to indicate that it is an autonomous message. See Table 13.

**8.2.5 INFORMATION field (# 5)**

The function of the INFORMATION field depends upon the settings of other message fields. The encoding indicated by DATA field and AUTONOMOUS MESSAGE field together (bits 3 and 5) indicate the function of the INFORMATION field. The valid encodings are summarized in Table 13.

**8.3 eoc message description**

Valid eoc messages and their opcodes are summarized in Table 14. The opcode values are given in hex (MSB left, LSB right) with the MSB mapping to bit eoc13 and the LSB to bit eoc6. The Direction D/U indicates that the message may be sent both in the downstream and upstream direction. The Direction D or U indicates that the message is transmitted in the downstream or upstream direction respectively.

**Table 14/G.992.2 – eoc message opcodes**

<b>Bidirectional eoc messages</b>			
<b>Value</b>	<b>Abbreviation</b>	<b>Direction</b>	<b>Opcode meaning</b>
01 <sub>16</sub>	HOLD	D/U	The message "Hold" tells the ATU-R to transition to the idle state and maintain any previously latched operations. This message may also be transmitted during the idle state.
F0 <sub>16</sub>	RTN	D/U	The message "Return to Normal" releases all outstanding eoc-controlled operations (latched conditions) at the ATU-R and returns the eoc protocol system to the idle state. This message may also be transmitted during the idle state.
02 <sub>16</sub>	SLFTST	D/U	The message "Self Test" requests the ATU-R to perform a self test. The result of the self test shall be stored in the self-test data result register.
07 <sub>16</sub>	REQCOR	D/U	The message requests the ATU-R to send corrupt crc bits to the ATU-C until cancelled by the "Request End of Corrupt crc" or "Return to Normal" message. This command shall be latching as per 8.3.1.
08 <sub>16</sub>	REQEND	D/U	The message requests the ATU-R to stop sending corrupt crc bits to the ATU-C.
0B <sub>16</sub>	NOTCOR	D/U	The message notifies the ATU-R that the ATU-C shall send corrupt crc bits until cancellation is indicated by "Notify End of Corrupted crc" or "Return to Normal". This command shall be latching as per 8.3.1.
0D <sub>16</sub>	NOTEND	D/U	The message notifies the ATU-R that the ATU-C has stopped sending corrupt crc bits.
0E <sub>16</sub>	EOD	D/U	The message "End of Data" is sent by the ATU-C as part of the eoc write protocol after it has sent all bytes of data to the ATU-R. This message has a slightly different meaning when sent by the ATU-R, as defined in 8.3.2.
13 <sub>16</sub>	REQTPU	D/U	This message requests the ATU-R to update the test parameter set as defined in 10.2. Test parameters supported by the ATU-R shall be updated and stored in a data register within 10 s after the request is received.
16 <sub>16</sub>	GNTPDN	D/U	This message is sent by the ATU-C to acknowledge a REQPDN from the ATU-R or to initiate a power down request itself. When the ATU-R receives GNTPDN, it uses the value of data register A to determine the power management link state granted by the ATU-C. See 13.4.
83 <sub>16</sub>	REJPDN	D/U	This message is sent by the ATU-C to acknowledge a REQPDN from the ATU-R. When the ATU-R receives REJPDN, it cancels its REQPDN request, and remains in the current link state. See 13.5.1.

**Table 14/G.992.2 – eoc message opcodes (continued)**

<b>Bidirectional eoc messages</b>			
<b>Value</b>	<b>Abbreviation</b>	<b>Direction</b>	<b>Opcode meaning</b>
(20 <sub>16</sub> , 23 <sub>16</sub> , 25 <sub>16</sub> , 26 <sub>16</sub> ) (29 <sub>16</sub> , 2A <sub>16</sub> , 2C <sub>16</sub> , 2F <sub>16</sub> ) (31 <sub>16</sub> , 32 <sub>16</sub> , 34 <sub>16</sub> , 37 <sub>16</sub> ) (38 <sub>16</sub> , 3B <sub>16</sub> , 3D <sub>16</sub> , 3E <sub>16</sub> )	WRITE	D/U	This write or receive message directs the ATU-R to enter the Data Write Protocol state, receive data, and write it in the data register specified by the Opcode. Opcode 20 <sub>16</sub> , and 3E <sub>16</sub> , correspond to data register 0 <sub>16</sub> , and F <sub>16</sub> , respectively.
(40 <sub>16</sub> , 43 <sub>16</sub> , 45 <sub>16</sub> , 46 <sub>16</sub> ) (49 <sub>16</sub> , 4A <sub>16</sub> , 4C <sub>16</sub> , 4F <sub>16</sub> ) (51 <sub>16</sub> , 52 <sub>16</sub> , 54 <sub>16</sub> , 57 <sub>16</sub> ) (58 <sub>16</sub> , 5B <sub>16</sub> , 5D <sub>16</sub> , 5E <sub>16</sub> )	READ	D/U	This read or send message directs the ATU-R to enter the Data Read Protocol state, read data from the data register specified by the Opcode, and transmit it to the ATU-C. Opcode 40 <sub>16</sub> and 5E <sub>16</sub> correspond to data register 0 <sub>16</sub> and F <sub>16</sub> , respectively.
<b>ATU-C to ATU-R (downstream) messages</b>			
<b>Value</b>	<b>Abbreviation</b>	<b>Direction</b>	<b>Opcode meaning</b>
10 <sub>16</sub>	NEXT	D/U	This message is sent multiply by the ATU-C (toggling bit four for multi-byte data until all data has been sent) while it is in Data Read Protocol state (i.e. after the ATU-R has acknowledged the previously sent Receive/Write Data command.
<b>ATU-R to ATU-C (upstream) messages</b>			
<b>Value</b>	<b>Abbreviation</b>	<b>Direction</b>	<b>Opcode meaning</b>
15 <sub>16</sub>	REQPDN	U	This is an autonomous message sent by the ATU-R to initiate a transition to a new power management link state. REQPDN is acknowledged by the ATU-C by optionally writing the value of the granted link state into data register A, and sending GNTPDN. Or, the ATU-C can send REJPDN to reject the requested link state. See 13.5.1.
E7 <sub>16</sub>	DGASP	U	This is an autonomous (i.e. unsolicited) message that the ATU-R may send to indicate the pending loss of link because the ATU-R has lost power; see 8.3.3.
04 <sub>16</sub>	UTC	U	This is a message is sent by the ATU-R to acknowledge receipt of eoc message that it cannot perform.



**Table 14/G.992.2 – eoc message opcodes (concluded)**

Reserved Opcodes			
Value	Abbreviation	Direction	Opcode meaning
(19 <sub>16</sub> , 1A <sub>16</sub> , 1C <sub>16</sub> , 1F <sub>16</sub> )		D/U	Four message opcodes are reserved for vendor proprietary use. The ATU-C shall read the Vendor ID (identification) code data register of the ATU-R to ensure compatibility between ATUs before using proprietary opcodes.
(80 <sub>16</sub> , 85 <sub>16</sub> , 86 <sub>16</sub> , 89 <sub>16</sub> , 8A <sub>16</sub> , 8C <sub>16</sub> , 8F <sub>16</sub> )			Reserved by ITU-T.

**8.3.1 Latching bidirectional eoc messages**

Some of the bidirectional eoc messages transmitted by the ATU-C are "latching" commands, meaning that a subsequent eoc message, transmitted from the ATU-C, shall be required to release the ATU-R from that state. Thus, multiple eoc-initiated actions can be in effect simultaneously. A separate command, "Return To Normal", is used to unlatch all latched states. This command is also used to bring the eoc protocol system to a known state, the Idle State, when no commands are active in the ATU-R location. To maintain the latched condition, the command "Hold State" shall be sent to bring the eoc protocol system to a known state, the Idle State.

**8.3.2 End of Data message (EOD)**

This message is sent by the ATU-C as part of the eoc write protocol after it has sent all bytes of data to the ATU-R.

This message may have a slightly different meaning when sent by the ATU-R. This message may be sent by the ATU-R:

- in response to an "End of Data" message from the ATU-C;
- in response to a "Next Byte" message from the ATU-C that is received after all bytes have been read from the currently addressed ATU-R register; or
- in response to a message from the ATU-C that contains a data byte after all bytes have been written to the currently addressed ATU-R register.

**8.3.3 Dying Gasp message (DGASP)**

The ATU-R shall have the ability to detect when the electrical power has been shut off. After such detection of a near-end Loss of Power (lpr) defect (see 10.3.2), the ATU-R shall insert priority eoc messages into the upstream data to implement a "dying gasp" as an lpr indicator.

At least six contiguous dying gasp eoc messages shall be inserted in the next (at least twelve) available upstream bytes available for eoc beginning with an even-numbered frame, regardless of the number of eoc frames received in the downstream channel.

The ATU-C shall not send a response to a "dying gasp" message back to the ATU-R. An lpr indicator is present at the ATU-C if at least four "dying gasp" messages are received within the last twelve contiguous upstream bytes available for eoc, beginning with the even-numbered frame (see Loss of Power primitive definition in 10.3.2). Sending the "dying gasp" shall not cause the ATU-R to change the eoc protocol state, nor shall receiving it cause the ATU-C to immediately change state.

### 8.3.4 Autonomous messages

Autonomous messages are unsolicited data transfers that can be initiated by either the ATU-C or ATU-R.

Autonomous messages can be inserted regardless of the state of the eoc protocol state machine and do not affect the eoc protocol state. An autonomous message allows for the transport of a single byte of data. Consecutive autonomous messages can be issued as soon as appropriate eoc bytes in the superframe are available. The flow of autonomous messages may be interrupted at any time for bidirectional, ATU-C to ATU-R or ATU-R to ATU-C eoc messages.

### 8.3.5 Data registers in the ATU-R

Table 15 summarizes the ATU-R data registers and their applications. The register numbers are given in hexadecimal. Use of some registers is restricted as read only. Some registers are multi-byte and shall be read most significant byte first. Registers 9<sub>16</sub> and B<sub>16</sub> through F<sub>16</sub> are reserved for future use by the ITU-T. The ATU-R shall respond with a UTC (Unable to Comply) if requested to read from or write to one of these registers.

**Table 15/G.992.2 – ATU-R data registers**

Number	Use	Length	Description
0 <sub>16</sub>	Read	8 bytes	ATU-R Vendor ID
1 <sub>16</sub>	Read	Vendor discretionary	ATU-R Revision number
2 <sub>16</sub>	Read	32 bytes	ATU-R Serial number (32 bytes): The format of the ATU-R Serial number is vendor discretionary.
3 <sub>16</sub>	Read	Vendor discretionary	Self Test Results: The most significant byte of the Self Test Results shall be 00 <sub>16</sub> if the selftest passed, and 01 hex if it failed (the meaning of "failure" is vendor discretionary); other values are reserved for future use. The length and syntax of the remainder are vendor discretionary.
4 <sub>16</sub>	Read/Write	Vendor discretionary	Vendor discretionary
5 <sub>16</sub>	Read/Write	Vendor discretionary	Vendor discretionary
6 <sub>16</sub>	Read	1 byte	Line attenuation: The line attenuation is defined in 10.4.
7 <sub>16</sub>	Read	1 byte	SNR Margin: The SNR margin is defined in 10.4.

**Table 15/G.992.2 – ATU-R data registers (concluded)**

Number	Use	Length	Description
8 <sub>16</sub>	Read	30 bytes	<p>ATU-R configuration: The ATU-R configuration data, as defined in 7.3, shall be read (one byte for each variable) in the following order:</p> <p>Downstream:</p> <p>Reserved, B<sub>I</sub>(AS0), reserved, reserved,  Reserved, reserved, reserved, reserved,  Reserved, reserved, reserved, reserved,  Reserved, reserved, reserved.</p> <p>Upstream:</p> <p>Reserved, B<sub>I</sub>(LS0), reserved, reserved,  reserved, reserved, reserved.</p> <p>Downstream:</p> <p>Reserved, RS<sub>I</sub>, S, D (RS<sub>I</sub> = R<sub>I</sub>/S)</p> <p>Upstream:</p> <p>Reserved, RS<sub>I</sub>, S, D (RS<sub>I</sub> = R<sub>I</sub>/S),  Reserved bytes shall be set to 00<sub>16</sub>.</p>
9 <sub>16</sub>	Reserved	Reserved	
A <sub>16</sub>	Read/Write	1 byte	<p>Link State: When a link state transition request is pending from the ATU-R, then the value of register A shall be set to the requested link state. At all other times, the value of register A shall contain the current power management link state.</p> <p>Link State encoding (hexadecimal):</p> <p>L0: 00<sub>16</sub>  L1: 01<sub>16</sub>  L3: 03<sub>16</sub></p> <p>Reserved by the ITU-T: 02<sub>16</sub> and 04-7F<sub>16</sub></p>
B-F <sub>16</sub>	Reserved	Reserved	

#### 8.4 eoc protocol

The eoc protocol operates in a repetitive command and response mode. The ATU-C acts as the master and issues bidirectional eoc messages. The ATU-R acts as slave and responds to the bidirectional messages issued by the ATU-C by echoing the message back to the ATU-C.

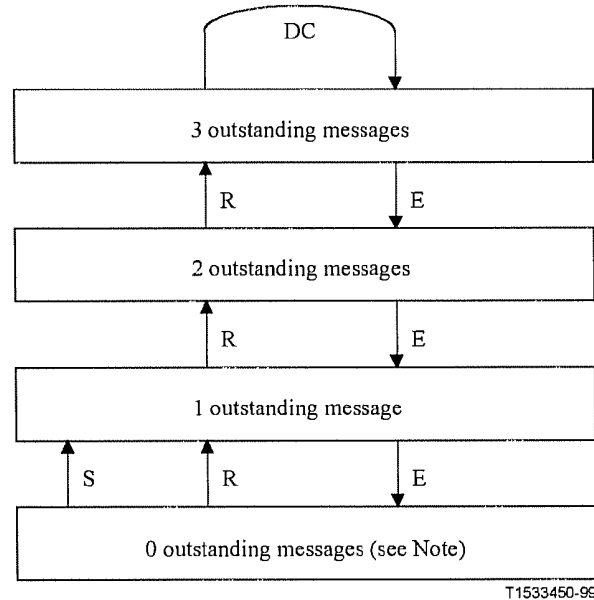
Three identical properly-addressed consecutive (i.e. no other eoc messages are received in between) messages shall be received before an action is initiated (both at ATU-C and ATU-R). Only one command and only three or fewer messages, under the control of the ATU-C, shall be outstanding (i.e. unacknowledged) at any one time.

NOTE – This restriction on the number of messages guarantees that an ATU-R with fewer opportunities to insert eoc frames into the upstream path will be able to acknowledge all eoc messages from the ATU-C.

Autonomous messages are transmitted transparent to the eoc protocol and do not change the protocol state at the ATU-R and ATU-C.

#### 8.4.1 Outstanding eoc messages

The procedure for dealing with outstanding messages at the ATU-C is shown in Figure 17. The ATU-C may only begin transmission of a new eoc message after reception of three consecutive ATU-R echoes of any current outstanding eoc message. When one or two messages are outstanding, the ATU-C may only repeat the previous message sent; thereby ensuring that all outstanding messages will be identical. Upon initialization, the ATU-C shall have no outstanding messages.



S Send new message  
 R Repeat last message  
 E EOC message received  
 DC Dummy code

NOTE – Immediately after initialization the ATU-C shall have no outstanding messages.

**Figure 17/G.992.2 – ATU-C state diagram for outstanding eoc messages**

For E, R, and S all the eoc messages with bit 5 set to 1<sub>b</sub> shall be considered. Other eoc messages shall not cause a change of state in the eoc state machine.

Whenever there are three outstanding messages, the ATU-C shall stop sending messages and stuff the available eoc bandwidth with "no synchronization action" bytes or autonomous message bytes. Sending eoc messages may be resumed after receiving one or more acknowledgements (echoes) from the ATU-R. Only one command shall be outstanding at any time. Therefore, all outstanding eoc messages shall be identical. To deal with eoc messages that are not echoed by the ATU-R (e.g. those that are erased from the line due to impulse noise and will therefore remain outstanding), the ATU-C shall implement an adequate error recovery mechanism. This mechanism does not affect interoperability and is therefore outside the scope of this Recommendation.

The eoc protocol state diagrams of the ATU-R and ATU-C shall be as shown in Figures 18 and 19.

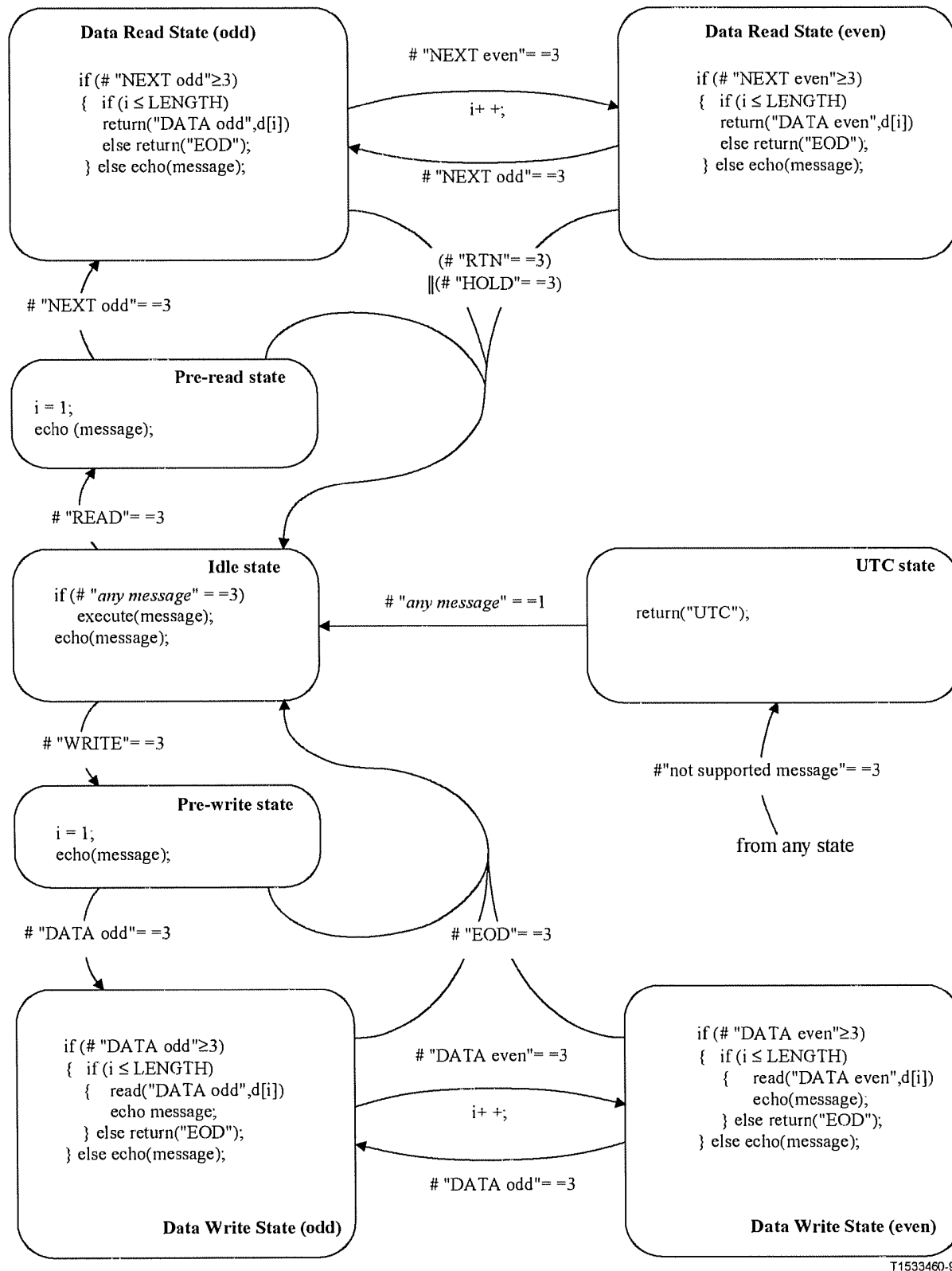


Figure 18/G.992.2 – eoc receiver state machine at ATU-R



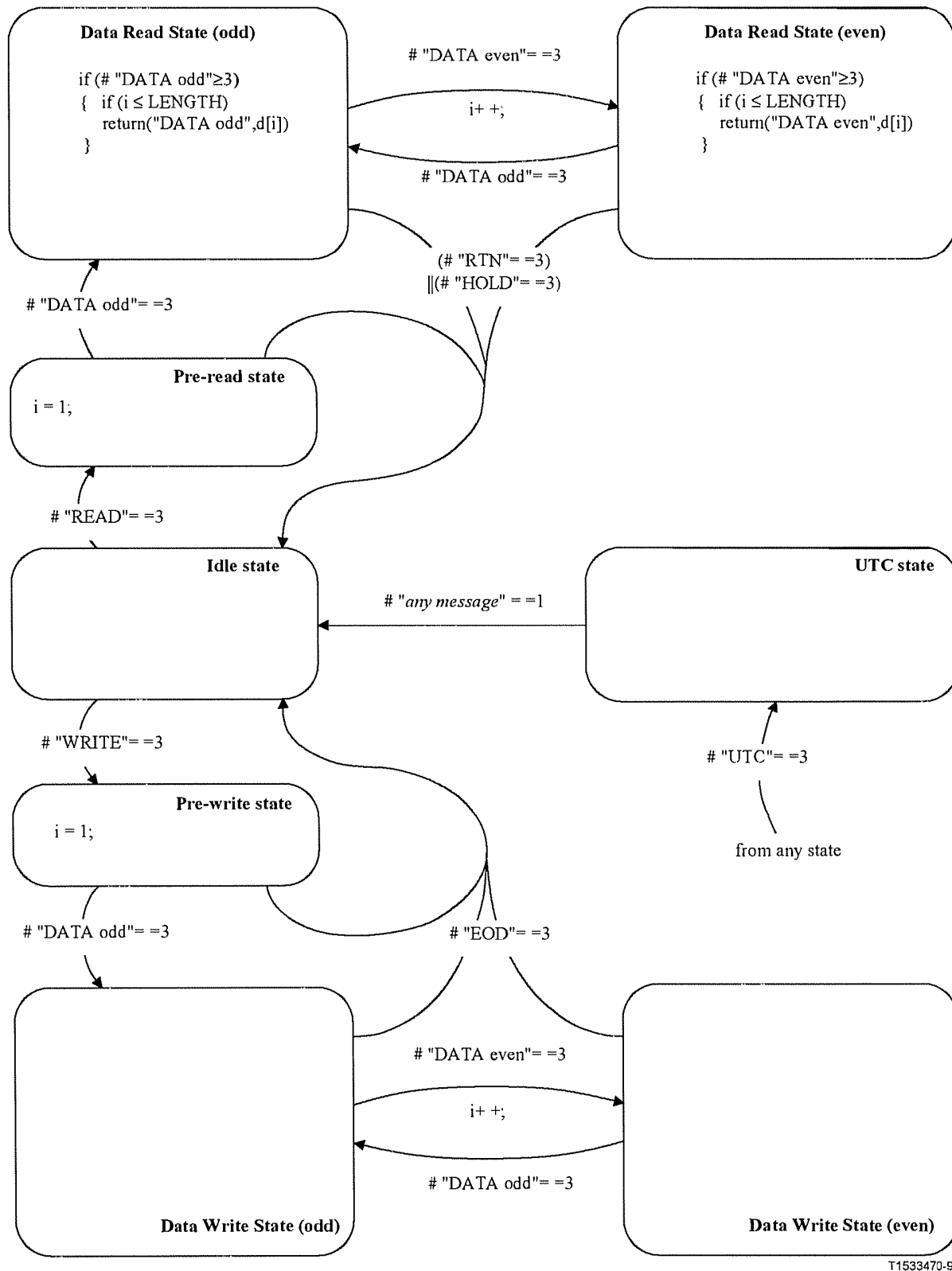


Figure 19/G.992.2 -- eoc receiver state machine at ATU-C

#### 8.4.2 eoc state transitions

The following shall govern state changes as shown in Figures 18 and 19.

- 1) The protocol state changes are performed based on received messages. At the ATU-C, received messages are responses from the ATU-R to messages sent from the ATU-C. Depending on the ATU-C receiver protocol state, the ATU-C transmitter message set may be restricted. It is left up to the ATU-C transmitter to organize and send a sequence of message such that the right response from the ATU-R is achieved based on the receiver protocol state machines.
- 2) ("message" = N) is true if and only if the previously received N messages are identical (i.e. all 13 bits equal) and properly addressed (i.e. having ATU-R address). ("message" = 1) means the most recently received message is different (in at least 1 out of 13 bits) from the immediately preceding message and is properly addressed.
- 3) Moving to another state (based on the message received) shall be considered first, then the (same or new) state shall be executed. At the ATU-R, execution of commands in the Idle state shall be as described in 8.3 (invoking latching, unlatching or self test).
- 4) All the eoc messages with bit 5 set to 1<sub>b</sub> shall be considered as received messages and cause an eoc response message at the ATU-R. Other eoc messages shall not cause a change of state in the eoc state machine and shall not cause an eoc response message at the ATU-R.

The responses allowed from the ATU-R fall into three categories:

- 1) message/echo-response protocol states: Idle State and EXE State;
- 2) message/Unable-to-Comply-response protocol state: UTC State;
- 3) message/data-response protocol states: Data Read States and Data Write States;
- 4) (Data Read States includes Pre-Read, Data Read odd and Data Read even states)  
(Data Write State includes Pre-Write, Data Write odd and Data Write even states).

Autonomous messages do not effect the eoc protocol states. The reception of the DGASP message at the ATU-C may however cause a reset at the ATU-C leading to an eoc state change at the ATU-C (e.g. to Idle State).

The eoc protocol shall enter the Message/Echo-response protocol state (Idle State) when the ATUs transition from the initialization and training sequence to steady state transmission. In order to cause the desired action in the ATU-R, the ATU-C shall repeat the message (without exceeding the limit of outstanding messages) until it receives three identical consecutive eoc message echoes from the ATU-R. This completes the command and response protocol, but the ATU-C may continue to send the same message thereafter. The command and response protocol for that message must be completed before a new message (containing a new command), which may induce a different protocol state in the ATU-R, may be issued.

At the ATU-R, depending on the state it is in, various restricted sets of eoc messages shall be acceptable. These sets shall be as shown in Table 16. Reception of other, inapplicable, messages shall result in an Unable to Comply (UTC) response to the ATU-C.

**Table 16/G.992.2 – eoc messages acceptable at the ATU-R**

ATU-R state	eoc messages acceptable at the ATU-R			
Idle	All messages acceptable			
UTC	All messages acceptable			
Data pre-read	Read	NEXT odd	RTN	HOLD
Data read odd, even	NEXT odd	NEXT even	RTN	HOLD
Data pre-write	WRITE	DATA odd	EOD	
Data write odd, even	DATA odd	DATA even	EOD	

**8.4.2.1 Message/Echo-response protocol state**

This state is identical to the Idle state shown in Figures 18 and 19. To initiate an action at the ATU-R, the ATU-C shall begin sending eoc messages with the Data/opcode set to 1<sub>b</sub> and with the appropriate message opcode in the information field.

The ATU-R shall initiate action when, and only when, three identical, consecutive, and properly addressed eoc frames that contain a message recognized by the ATU-R have been received. The ATU-R shall respond to all received messages. The response shall be an echo of the received ADSL eoc message. The combination of the ATU-C sending an ADSL eoc frame and the ATU-R echoing the frame back comprises the Message/Echo-response protocol state.

For the ATU-C to confirm correct reception of the message by the ATU-R, the message/echo-response ADSL eoc protocol state is repeated until the ATU-C receives three identical and consecutive echoes. This serves as an implicit acknowledgement to the ATU-C that the ATU-R has correctly received the transmitted message and is acting on it. This completes the Message/Echo-response protocol state.

The ATU-C continuously sends the activating message after the receipt of the three valid echoes, or alternatively, it may switch to sending the "Hold State" message. If the message was one of the latching commands, then the ATU-R shall maintain the commanded condition until the ATU-C issues the appropriate command that ends the specific latched condition or until the ATU-C issues the "Return to Normal" command (at which time all latched conditions in the ATU-R shall be terminated).

**8.4.2.2 Message/Unable-to-Comply response protocol state**

When the ATU-R does not support a message that it has received three times identically and consecutively, it shall respond with the Unable to Comply (UTC) ADSL eoc response message with its own address in lieu of a third identical and consecutive echo. In this manner the ATU-R will switch to the message/UTC-response protocol state.

The transmission by the ATU-R and reception by the ATU-C of three identical, consecutive, properly-addressed Unable to Comply messages constitutes notification to the ATU-C that the ATU-R does not support the requested function, at which time the ATU-C may abandon its attempt.

**8.4.2.3 Data Read State**

To read data from the ATU-R, the ATU-C shall issue a bidirectional READ eoc message to the ATU-R that specifies the register to be read.

The ATU-C shall then request the first byte to be sent from the ATU-R by sending "Next Byte" messages with bit 4 set to 1<sub>b</sub>, indicating a request for an "odd" byte. The ATU-R shall respond to these "Next Byte" messages by echoing them until it has received three such messages consecutively, identically and properly addressed. Beginning with the third such reception, the ATU-R shall respond to the read request by sending the first byte of the register in the

INFORMATION field of the "Next Byte" echo message. The ATU-C continues to send the "Next Byte" message and the ATU-R continues to respond with the "Next Byte" echo message containing the first byte of data in the INFORMATION field until the ATU-C has received at least three consecutive, identical and properly addressed data frames with bit 4 set to indicate "odd byte".

If there are more data to be read, the ATU-C shall request the second byte of data by sending "Next Byte" messages with bit 4 set to 0<sub>b</sub> ("even byte"), repeating the procedure defined above for reading the first byte from the register.

The procedure using the "Next Byte" message continues for the third and all subsequent bytes with the value of bit 4 toggling from "odd byte" to "even byte" or vice versa, on each succeeding byte. Each time bit 4 is toggled, the ATU-R echoes for two correct frames, and starts sending the data frame on the third reception. The process ends only when all data in the register has been read.

To continue reading data, once the ATU-R is in the Data Read odd or even State, the only message that the ATU-C is allowed to send is the "Next Byte" message with bit 4 toggling. To end the data read state abnormally, the ATU-C sends either "Hold State" or "Return to Normal", depending on whether any latched states are to be retained. If the ATU-R receives any other message three times consecutively, identically and properly addressed while it is in Data Read odd or even State, it shall go into the UTC State.

If, after all bytes have been read from the ATU-R register, the ATU-C continues to send the "Next Byte" message with bit 4 toggled, then the ATU-R shall send an "End of Data" message (with bit 3 set to 1<sub>b</sub> indicating opcode) beginning with the third such reception.

For the ATU-C, the data read state ends either when the ATU-C has received the last requested data byte three times consecutively, identically and properly addressed, or when the ATU-C has received three consecutive, identical and properly addressed "End of Data" messages with bit 3 set to 1<sub>b</sub>. The ATU-C shall then switch itself and the ATU-R over to the Idle State with the "Hold State" or "Return to Normal" message, and the ATU-R shall release the register and leave the Data Read State after receiving three identical, consecutive and properly addressed "Hold State" or "Return to Normal" messages.

#### **8.4.2.4 Data Write State**

To write data to the ATU-R's memory, the ATU-C shall issue a bidirectional WRITE eoc message to the ATU-R that specifies the register to be written. When the ATU-R acknowledges with three consecutive, identical and properly addressed echo messages, the ATU-C sends the first byte of data by transmitting the DATA eoc message. The ATU-R shall acknowledge the receipt of the byte with an echo of the message. After the ATU-C is satisfied with three identical, consecutive and properly addressed echo responses, it shall start sending the next byte of data. Each time the ATU-C receives at least three identical and consecutive correct data echo responses, it shall switch to sending the next byte of data. It shall also toggle the "odd/even" bit accordingly. The ATU-C shall end the Data Write State with the EOD eoc message indicating to the ATU-R to return to the Idle State.

To continue writing data, once the ATU-R is in the Data Write odd or even State, the only message that the ATU-C is allowed to send is the DATA eoc message. If the ATU-R receives any other message three times consecutively, identically and properly addressed while it is in Data Write state, it shall go into the UTC state.

If, after all bytes have been written to the ATU-R register, the ATU-C continues to send a next byte of data, then the ATU-R shall send an EOD eoc message beginning with the third such reception.

## **8.5 Clear eoc**

Support of the autonomous data messages is mandatory. It provides the channel defined in 6.1/G.997. The channel is provided in both the upstream and the downstream direction by transmission of autonomous messages with eoc field settings as shown in Table 13.

These autonomous data messages may be transmitted from either the ATU-C or the ATU-R and are transparent to the current state of the eoc states machine. That is, these autonomous data messages transporting clear channel data can be inserted regardless of the current state of the eoc state machine. There is no requirement that these autonomous data messages be inserted contiguously. That is, other eoc messages may be inserted between any two autonomous data messages. There is also no requirement for any specific rate of insertion of autonomous data messages into the eoc.

When a clear eoc data byte is received, the byte payload is placed in a buffer on the receiving ATU. Assembly into PDUs is defined in Recommendation G.997.1.

The clear eoc does not support flow control. It is assumed that a higher level protocol implemented over this data path will support a flow control mechanism if required. Additionally, any system implementing a stack and application using the clear eoc (such as that defined in Recommendation G.997.1) should disable, at the higher layers, the further sending of autonomous data frames should a significant number of these higher layer messages be left without response from the receiver.

## **9 ADSL overhead channel**

### **9.1 The ADSL Overhead Control (aoc) channel introduction**

Thirty-two bytes are allocated per superframe for transmission of aoc data. The multiplexing of the aoc channel into the superframe is described in 7.3.3.1.1.2. The aoc channel is used for bit-swapping and fast retrain profile management. Bit swapping enables an ADSL system to change the number of bits assigned to a subcarrier, or change the transmit energy of a subcarrier without interrupting data flow. Fast retrain allows the ATU transceivers to quickly change transmission characteristics during changing line conditions.

All bit swap actions taken upon the ATU transceivers, after acknowledgement from the aoc channel, are coordinated between the ATU receiver and ATU transmitter by superframe counting.

#### **9.1.1 Bit swap channel**

The bit swap process uses the aoc channel. All bit swap messages shall be repeated five consecutive times over the aoc channel.

#### **9.1.2 Superframe counting**

The transceivers coordinate bit swapping at the receiver and transmitter by counting superframes. The ATU transmitters and receivers shall start superframe counters immediately upon entering SHOWTIME from either initialization or fast retrain.

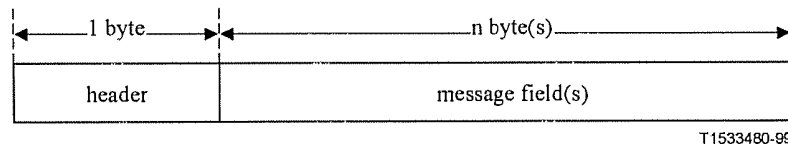
Superframe counting starts with the first superframe at beginning of SHOWTIME being superframe 0. Each transmitter shall increment its counter after transmission of a superframe. Superframe counting is performed MOD 256 in both transmitter and receiver.

Synchronization of the corresponding transmitter and receiver superframe counters is maintained using the synchronization symbol in the superframe structure. Any form of restart that requires a transition from initialization or fast retrain to SHOWTIME shall reset the superframe counter.



## 9.2 aoc message encoding

An aoc message consists of an aoc header and an aoc message field as shown in Figure 20.



**Figure 20/G.992.2 – aoc message encoding**

### 9.2.1 aoc message header encoding

The type of aoc message is identified by an eight-bit header. Table 17 summarizes valid aoc message headers. For example, in the case of a bit swap, the aoc header binary 1111111<sub>b</sub> will be detected, and the next byte of aoc data shall determine whether the message is a bit swap request or a bit swap acknowledge. A block of aoc header values (binary 1100xxxx<sub>b</sub>) is reserved for vendor-specific aoc messages.

**Table 17/G.992.2 – aoc message headers**

aoc message header	aoc message field total length including aoc message header (bytes)	Interpretation
00001111 <sub>b</sub>	Undefined	Reserved by ITU-T
1100xxxx <sub>b</sub>	Undefined	Vendor-specific message
11110000 <sub>b</sub>	1	Unable to comply message (UTC)
11111100 <sub>b</sub>	13	Extended bit swap request message
11111111 <sub>b</sub>	9	Bit swap request message
11111111 <sub>b</sub>	3	Bit swap acknowledge message
00000011 <sub>b</sub>	3	Profile management request
00000011 <sub>b</sub>	3	Profile management acknowledge

The header byte values are given in binary format (MSB left, LSB right) and represent aoc7-aoc0 bits (MSB in bit 7, LSB in bit 0) as carried in the SB. All other bytes in the aoc message shall be mapped according to the same convention.

### 9.2.2 Profile Management Request

The Profile Management Request message (Table 18) is sent by the ATU-R (or ATU-C) to request the ATU-C (or ATU-R) to save the current settings in a profile. Allowed values for yyyy<sub>b</sub> are from 0000<sub>b</sub> to 1111<sub>b</sub> corresponding to profile 0 and profile 15 respectively.

**Table 18/G.992.2 – Format of the Profile Management Request message**

Message header	Message field	
00000011 <sub>b</sub> (1 byte)	Command 00000001 <sub>b</sub> (1 byte)	Data 0000yyyy <sub>b</sub> (1 byte)
Interpretation: Save current profile as profile n = yyyy <sub>b</sub>		

### 9.2.3 Profile Management Acknowledge

The Profile Management Acknowledge message (Table 19) is sent by the ATU-C or ATU-R to acknowledge a Profile Management Request message from the ATU-R or ATU-C. The acknowledge message shall contain the same save profile number (n = yyyy<sub>b</sub>) as in the corresponding Profile Management Request message. Allowed values for xxxx<sub>b</sub> and yyyy<sub>b</sub> are from 0000<sub>b</sub> to 1111<sub>b</sub> corresponding to profile 0 and profile 15 respectively.

**Table 19/G.992.2 – Format of the Profile Management Acknowledgement message**

Message header	Message field	
00000011 <sub>b</sub> (1 byte)	Command 00000010 <sub>b</sub> (1 byte)	Data xxxxyyyy <sub>b</sub> (1 byte)
Interpretation: Current profile saved as profile n = yyyy <sub>b</sub> . Highest profile number supported is m = xxxx <sub>b</sub> .		

If the ATU-C (or ATU-R) cannot perform the requested save operation (e.g. because of too high a requested n value), an UTC message shall be returned.

### 9.2.4 Bit swap request message encoding

This message tells the transmitter which subcarriers are to be modified. The format of the request is shown in Table 20.

**Table 20/G.992.2 – Format of the bit swap request message**

Message header	Message fields 1-4	
11111111 <sub>b</sub> (1 byte)	Command (1 byte)	Subcarrier index (1 byte)

The request shall comprise nine bytes as follows:

- An aoc message header consisting of eight binary ones.
- Message fields 1-4, each of which each consists of an eight-bit command followed by a related eight-bit subcarrier index. Valid eight-bit commands for the bit swap message shall be as shown in Table 21. The eight-bit subcarrier index is counted from low to high frequencies with the lowest frequency subcarrier having the number zero. The subcarrier index zero shall not be used.

**Table 21/G.992.2 – Bit swap request commands**

Value	Interpretation
00000000 <sub>b</sub>	Do nothing
00000001 <sub>b</sub>	Increase the number of allocated bits by one
00000010 <sub>b</sub>	Decrease the number of allocated bits by one
00000011 <sub>b</sub>	Increase the transmitted power by 1 dB
00000100 <sub>b</sub>	Increase the transmitted power by 2 dB
00000101 <sub>b</sub>	Increase the transmitted power by 3 dB
00000110 <sub>b</sub>	Reduce the transmitted power by 1 dB
00000111 <sub>b</sub>	Reduce the transmitted power by 2 dB
00001xxx <sub>b</sub>	Reserved for vendor-discretionary commands

To avoid  $g_i$  divergence between ATU-C and ATU-R after several bit swaps, for a  $g_i$  update of  $\Delta$  dB the new  $g_i$  value should be given by:

$$g_i' = (1/512) \times \text{round} (512 \times g_i \times 10^{(\Delta/20)})$$

### 9.2.5 Extended bit swap request message encoding

Any on-line adaptation may be encoded in an extended bit swap request. However, because a single-bit subcarrier is not allowed, an extended bit swap request containing six fields shall be used when decreasing the number of bits on a subcarrier from two to zero, or when increasing the number of bits on a subcarrier from zero to two. The format of this extended bit swap request is similar to that of the bit swap request, but the number of message fields is increased to six, and a different message header is used. The format of the request is shown in Table 22.

**Table 22/G.992.2 – Format of the extended bit swap request message**

Message header	Message fields 1-6	
11111100 <sub>b</sub> (1 byte)	Command (1 byte)	Subcarrier index (1 byte)

The receiver shall initiate an extended bit swap by sending an extended bit swap request message to the transmitter. This request tells the transmitter which subcarriers are to be modified. The extended bit swap request message shall comprise 13 bytes as follows:

- an eight bit extended bit swap request message header of 11111100<sub>b</sub>;
- six message fields, one to six, each of which is defined as in Table 22.

The receiver shall use two identical message fields to request a zero-to-two increase or a two-to-zero decrease of the number of bits on a subcarrier, according to the allowable bit-swap commands defined in Table 21.

### 9.2.6 Bit swap acknowledge message encoding

A bit swap acknowledge message (Table 23) shall contain the following:

- a bit swap acknowledge message header coded 11111111<sub>b</sub>;

- one message field, which consists of an eight-bit bit swap acknowledge command followed by an eight-bit superframe counter number. The acknowledge command shall be coded as 11111111<sub>b</sub>. The superframe counter number indicates when the bit swap is to take place. This number shall be at least 47 greater than the counter number when the request was received (this corresponds to a minimum wait time of 800 ms).

The new bit and/or transmit power table(s) shall then take effect starting from the first frame (frame 0) of an ADSL superframe, after the specified superframe counter number has been reached. That is, if the bit swap superframe counter number contained in the bit swap acknowledge message is  $n$ , then the new table(s) shall take effect starting from frame 0 of the  $(n + 1)$ th ADSL superframe.

**Table 23/G.992.2 – Format of the bit swap acknowledge**

Message header	Message field	
	Acknowledge command	Bit swap superframe Counter number
11111111 <sub>b</sub> (1 byte)	11111111 <sub>b</sub> (1 byte)	$n$ (1 byte)

### 9.3 Bit swap operation

Either ATU may initiate a bit swap by transmitting the bit swap request message. The bit swapping procedures in the upstream and downstream channels are independent, and may take place simultaneously.

An ATU receiver is the initiator of a bit swap procedure. It may transmit a bit swap (extended or simple) request message and receives the bit swap acknowledge message. The ATU transmitter responds to the reception of a bit swap request message and shall transmit either the bit swap acknowledge or the Unable to Comply message.

#### 9.3.1 Bit swap – Receiver

The receiver shall start a time-out of  $500 \pm 20$  ms from the moment it sends a bit swap request message. When neither an acknowledgement nor an UTC message has been detected in this time-out interval, the receiver shall resend a bit swap request message (which shall have the same parameters) and restart the timeout. Only when an acknowledgement has been detected within the time-out interval shall the receiver prepare for a bit swap at the time specified in the acknowledge message.

The receiver shall then wait until the superframe counter equals the value specified in the bit swap acknowledge message. Then, beginning with frame 0 of the next ADSL superframe, the receiver shall change the bit assignment of the appropriate subcarriers and perform tone reordering based on the new subcarrier bit assignment and update applicable receiver parameters of the appropriate subcarriers to account for a change in their transmitted energy.

Upon time-out, the bit swap message shall be re-transmitted. However, after a finite (implementation dependent) number of unsuccessful retries, the receiver shall take recovery actions to restore the aoc channel.

A new bit swap request shall only be sent after the previous bit swap has taken place or has been denied by a UTC message or when the  $500 \pm 20$  ms time-out has occurred while waiting for a bit swap acknowledge.

### 9.3.2 Bit swap – Transmitter

Within 400 ms after reception of the bit swap request, the transmitter shall send either a bit swap acknowledge message or a UTC (Unable to Comply) message. The transmitter should and is recommended to send the bit swap acknowledge message in case the aoc protocol is operating in a reliable environment e.g. with a filter as shown in this Recommendation's reference model or a splitter as shown in the Recommendation G.992.1 reference model. In other cases, the transmitter may send a UTC message. Mandating the transmitter to send a bit swap acknowledge message is for further study.

After transmitting the bit swap acknowledge, the transmitter shall wait until the superframe counter equals the value specified in the bit swap acknowledge. Then, beginning with DF 0 of the next ADSL superframe, the transmitter shall change the bit assignment of the appropriate subcarriers, and perform tone re-ordering based on the new subcarrier bit assignment and change the transmit energy in the appropriate subcarriers by the desired factor.

If the transmitter receives a new bit swap request message while waiting for the superframe counter to equal the value specified in the last bit swap acknowledge message, it shall immediately stop waiting and update the superframe counter for bit swap according to the new message. It shall restart the process for the newly arrived bit swap request message assuming that the new message equals the previous.

### 9.4 aoc protocol

When the aoc channel is idle, i.e. there are no aoc messages to be transported, the aoc shall insert 00000000<sub>b</sub> as a stuffing pattern in the aoc SB bytes. Hence, an aoc message begins with a non-zero byte.

aoc messages shall be transmitted five consecutive times (i.e. five concatenated and identical messages without aoc stuffing patterns in between) for extra reliability. At least 20 aoc stuffing patterns shall be inserted between two consecutive groups of five concatenated and identical messages.

An ATU receiving an aoc message shall act on that aoc message only if it has received three identical messages in a time period spanning five of that particular message. When an ATU receives an unrecognizable command, it shall take no action.

In the case when a function is requested but cannot be performed by either the ATU-C or the ATU-R for any reason (e.g. to save a profile with profile number greater than support) an unable to comply message ("11110000<sub>b</sub>") shall be issued.

There shall be a maximum of one downstream and one upstream aoc message outstanding at any time.

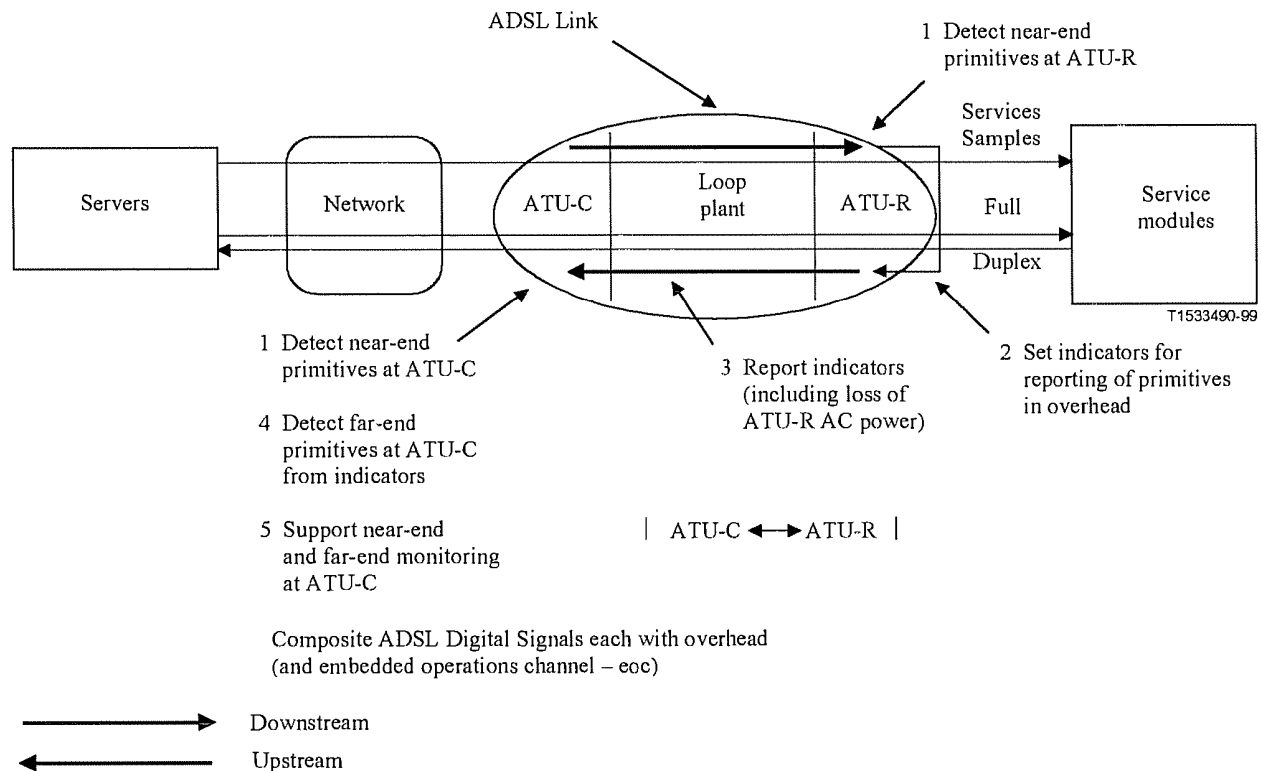
## 10 In-service performance monitoring and surveillance

The following terminology is used in this clause for description of the in-service performance monitoring and surveillance functions (see Figure 21):

- *Near-end*: Near-end means performance of the loop-side received signal at the input of the ATU.
- *Far-end*: Far-end means performance of the downstream loop-side received signal at the input of the ATU-R, where this performance is reported to the ATU-C in upstream indicator bits or performance of the upstream loop-side received signal at the input of the ATU-C, where this performance is reported to the ATU-R in downstream overhead indicator bits; this case is a mirror image of the above.



- *Primitives*: Primitives are basic measures of performance, usually obtained from digital signal line codes and frame formats, or as reported in overhead indicator bits from the far-end. Performance primitives are categorized as events, anomalies and defects. Primitives may also be basic measures of other quantities (e.g. ac or battery power), usually obtained from equipment indicators.
- *Anomalies*: An anomaly is a discrepancy between the actual and the desired characteristics of an item. The desired characteristics may be expressed in the form of a specification. An anomaly may or may not affect the ability of an item to perform a required function. Performance anomalies are defined in 10.1.
- *Defects*: A defect is a limited interruption in the ability of an item to perform a required function. It may or may not lead to maintenance action depending on the results of additional analysis. Successive anomalies causing a decrease in the ability of an item to perform a required function are considered as a defect.
- *Thresholds*: See clause 8/G.997.1.
- *Threshold Crossing Alert*: See Recommendation G.997.1.
- *Indicator*: An indicator is the message or bits that are transmitted from the ATU-R to signal a far-end primitive anomaly or defect.



**Figure 21/G.992.2 – In-service surveillance of the ADSL link shown from the standpoint of the ATU-C**

ADSL systems have been designed to deliver packet-/cell-based payloads. The performance monitoring capabilities required to maintain those systems are imbedded within the packet/cell systems. The ADSL system shall support the data path monitoring requirements as required by the specific payload technology.

## 10.1 ADSL line related primitives

### 10.1.1 ADSL line related near-end anomalies

Two near-end anomalies are defined:

- *Forward error correction (fec)-i*: An fec-i anomaly occurs when a received FEC codeword for the data stream indicates that errors have been corrected;
- *Cyclic redundancy check (crc)-i*: A crc-i anomaly occurs when a received CRC-8 code for the superframe is not identical to the corresponding locally generated code.

### 10.1.2 ADSL line related far-end anomalies

Two far-end anomalies are defined:

- *Far-end forward error correction (ffec)-i*: An ffec-i anomaly is an fec-i anomaly detected at the far-end that is reported once per superframe by the fecc-i indicator bit. The fecc-i indicator bit shall be set to 1<sub>b</sub> to indicate that no fec-i anomaly is present in the previous superframe and shall be set to 0<sub>b</sub> to indicate that at least one fec-i anomaly is present in the previous superframe. An ffec-i anomaly occurs when a received fecc-i indicator bit is coded to 0<sub>b</sub>. A ffec-i anomaly terminates when a received fecc-i indicator bit is coded to 1<sub>b</sub>.
- *Far-end Block Error (febe-i) anomaly*: A febe-i anomaly is a crc-i anomaly detected at the far-end and is reported once per superframe by the febe-i indicator bit. The febe-i indicator shall be set to 1<sub>b</sub> to indicate that no crc-i anomaly is present in the previous superframe and shall be set to 0<sub>b</sub> to indicate that a crc-i anomaly is present in the previous superframe. A febe-i anomaly occurs when a received febe-i indicator is coded to 0<sub>b</sub>. A febe-i anomaly terminates when a received febe-i indicator is coded to 1<sub>b</sub>.

### 10.1.3 ADSL line related near-end defects

Two near-end defects are defined:

- *Loss of signal (los)*: A reference power is established by averaging the ADSL power over a 0.1 s period and over a subset of tones after the start of steady state data transmission (i.e. after initialization), and a threshold shall be set at 6 dB below this. A los defect occurs when the level of the received ADSL power, averaged over a 0.1 s period and over the same subset of tones, is lower than the threshold, and terminates when measured in the same way it is at or above the threshold. The subset of tones over which the ADSL power is averaged, is implementation discretionary and may be restricted at the ATU-R to only the downstream pilot tone.
- *Severely errored frame (sef)*: An sef defect occurs when the content of two consecutively received synchronization symbols does not correlate with the expected content over a subset of the tones. An sef defect terminates when the content of two consecutively received synchronization symbols correlate with the expected contents over the same subset. The correlation method, the selected subset of tones, and the threshold for declaring these defect conditions are implementation discretionary.

### 10.1.4 ADSL line related far-end defects

Two far-end defects are defined:

- *Far-end Loss of signal (los)*: A far-end los defect is a los defect detected at the far-end and is reported by the los indicator bit. The los indicator bit shall be set to 1<sub>b</sub> to indicate that no los defect is being reported and shall be set to 0<sub>b</sub> for six consecutive superframes to indicate that a los defect is being reported. A far-end los defect occurs when four or more out of six

contiguous los indicators are received coded as 0<sub>b</sub>. A far-end los defect terminates when four or more out of six contiguously received los indicators are coded as 1<sub>b</sub>.

- *Far-end Remote defect indication (rdi)*: An rdi defect is a sef defect detected at the far-end and is reported once per superframe by the rdi indicator bit. The rdi indicator bit shall be set to 1<sub>b</sub> to indicate that no sef defect is present in the previous superframe and shall be set to 0<sub>b</sub> to indicate that a sef defect is present in the previous superframe. An rdi defect occurs when a received rdi indicator is coded as 0<sub>b</sub>. An rdi defect terminates when a received rdi indicator is coded as 1<sub>b</sub>.

## 10.2 ATM data path related primitives

### 10.2.1 ATM data path related near-end anomalies

Three near-end anomalies are defined:

- *No Cell Delineation (ncd-i) anomaly*: An ncd-i anomaly occurs immediately after ATM Cell TC start-up when ATM data are allocated to the data buffer and as long as the cell delineation process operating on this data is in the HUNT or PRESYNC state. Once cell delineation is acquired, subsequent losses of cell delineation shall be considered ocd-i anomalies.
- *Out of Cell Delineation (ocd-i) anomaly*: An ocd-i anomaly occurs when the cell delineation process operating on these data transitions from SYNC to HUNT state. An ocd-i anomaly terminates when the cell delineation process transitions from PRESYNC to SYNC state or when the lcd-i defect maintenance state is entered.
- *Header Error Check (hec-i) anomaly*: An hec-i anomaly occurs when an ATM cell header error check fails on the interleaved data.

### 10.2.2 ATM data path related far-end anomalies

Three far-end anomalies are defined:

- *Far-end No Cell Delineation (fncd-i) anomaly*: An fncd-i anomaly is a ncd-i anomaly detected at the far-end and is reported once per superframe by the ncd-i indicator bit. The ncd-i indicator bit shall be set to 1<sub>b</sub> to indicate no ncd-i anomaly or ocd-i anomaly or lcd-i defect is present in the previous superframe and shall be set to 0<sub>b</sub> to indicate that at least one ncd-i anomaly or ocd-i anomaly or lcd-i defect is present in the previous superframe. An fncd-i anomaly occurs immediately after ATU start-up and terminates if a received ncd-i indicator is coded as 1<sub>b</sub>.
- *Far-end Out of Cell Delineation (focd-i) anomaly*: An focd-i anomaly is an ocd-i anomaly detected at the far-end and is reported once per superframe by the ncd-i indicator. An focd-i anomaly occurs if no fncd-i anomaly is present and a received ncd-i indicator bit is coded as 0<sub>b</sub>. A focd-i anomaly terminates if a received ncd-i indicator bit is coded set to 1<sub>b</sub>.
- *Far-end Header Error Check (fhfec-i) anomaly*: An fhfec-i anomaly is an hec-i anomaly detected at the far-end and is reported once per superframe by the hec-i indicator. The hec-i indicator shall be set to 1<sub>b</sub> to indicate that no hec-i anomaly is present in the previous superframe and shall be set to 0<sub>b</sub> to indicate that at least one hec-i anomaly is present in the previous superframe. An fhfec-i anomaly occurs when a received hec-i indicator bit is coded as 0<sub>b</sub>. An fhfec-i anomaly terminates when a received hec-i indicator is coded as 1<sub>b</sub>.

NOTE – The hec-i anomalies are reported once per superframe. This results in a low granularity of hec anomaly reporting since hundreds of ATM cells may be received over a one superframe time period.

### 10.2.3 ATM data path related near-end defects

One near-end defect is defined:

- *Loss of Cell Delineation (lcd-i) defect*: An lcd-i defect occurs when at least one ocd-i anomaly is present in each of four consecutive superframes and no sef defect is present. An lcd-i defect terminates when no ocd-i anomaly is present in four consecutive superframes.

### 10.2.4 ATM data path related far-end defects

One far-end defect is defined:

- *Far-end Loss of Cell Delineation (flcd-i) defect*: An flcd-i defect is an lcd-i defect detected at the far-end and is reported by the ncd-i indicator bit. An flcd-i defect occurs when an focd-i anomaly is present and four consecutively received ncd-i indicators are coded 0<sub>b</sub> and no rdi defect is present. An flcd-i defect terminates if four consecutively received ncd-i indicators are coded as 1<sub>b</sub>.

## 10.3 Other ADSL indicators, parameters and signals

### 10.3.1 Other near-end primitives

One near-end primitive is defined:

- *Loss-of-power (lpr)*: An lpr primitive occurs when the ATU electrical supply (mains) power drops to a level equal to or below the manufacturer-determined minimum power level required to ensure proper operation of the ATU. An lpr primitive terminates when the power level exceeds the manufacturer-determined minimum power level.

### 10.3.2 Other far-end primitives

One far-end primitive is defined:

- *Far-end Loss-of-power (lpr)*: A far-end lpr primitive is an lpr primitive detected at the far-end and is reported by the lpr indicator. The lpr indicator shall be coded with emergency priority in the next six available outgoing eoc messages (see the eoc protocol for "dying gasp". A far-end lpr primitive occurs when an lpr indicator is received. A far-end lpr primitive terminates if for a period of 0.5 s no lpr indicator is received and no near-end los defect is present. The condition for an lpr indicator being received is defined in the eoc protocol for "dying gasp".

### 10.3.3 Failure count parameters

The ATU-C shall provide near-end and far-end failure counters for each near-end and far-end failure defined in Recommendation G.997.1. The ATU-R may optionally provide near-end and far-end failure counters. See Recommendation G.997.1.

A particular failure count is the number of occurrences of a particular failure event, where a failure event occurs when the failure is declared, and ends when the failure clears.

## 10.4 Test parameters

The attenuation (ATN) and signal-to-noise ratio (SNR) margin test parameters apply to on-demand test requests; e.g. to check for adequate physical media performance margin at acceptance and after repair verification, or at any other time following the execution of initialization and training sequence of the ADSL system. ATN and SNR, as measured by the receivers at both the ATU-C and the ATU-R shall be externally accessible from the ATU-C, but they are not required to be continuously monitored. They are made available on demand as defined in 8.3.

### 10.4.1 Near-end test parameters

The following near-end test parameters shall be provided at the ATU-C and the ATU-R:

- **Attenuation (ATN):** The attenuation is the difference in dB between the power received at the near-end and that transmitted from the far-end. Received signal power in dBm is the sum of all data-carrying (i.e.  $b_i > 0$ ) DMT subcarrier powers averaged over a 1 s period. Transmitted signal power is  $-3.65 - 2n + 10\log(\sum g_i^2)$  dBm, summed over the data-carrying subcarriers. The attenuation ranges from 0 to 63.5 dB with 0.5 dB steps.
- **Signal-to-Noise Ratio (SNR) margin:** The signal-to-noise ratio margin represents the amount of increased received noise (in dB) relative to the noise power that the system is designed to tolerate and still meet the target BER of  $10^{-7}$ , accounting for all coding (e.g. trellis coding, RS FEC) gains included in the design. The SNR margin ranges from -64.0 dB to +63.5 dB with 0.5 dB steps.

### 10.4.2 Far-end test parameters

The following far-end test parameters shall be provided at the ATU-C:

- **Far-end Attenuation (ATN):** The far-end attenuation is the attenuation measured at the far-end. It can be read from the EOC ATN register using the EOC command set (see 8.3.5). The EOC ATN register shall be coded as an unsigned integer, ranging from 0 to 127, corresponding to a 0 to 63.5 dB attenuation (0.5 dB steps).
- **Far-end Signal-to-Noise Ratio (SNR) margin:** The far-end signal-to-noise ratio margin is the signal-to-noise ratio margin measured at the far-end. It can be read from the EOC SNR register using the EOC command set (see 8.3.5). The EOC SNR register shall be coded as a twos complement signed integer, ranging from -128 to +127, corresponding to a -64 to +63.5 dB signal-to-noise ratio margin (0.5 dB steps).

## 10.5 Other failures and parameters

Other failure, performance monitoring functions, network element configuration, test, diagnostic and status parameters are defined in Recommendation G.997.1.

## 11 Initialization

### 11.1 Overview

#### 11.1.1 Basic functions of initialization

ADSL transceiver initialization is required in order for a physically connected ATU-R and ATU-C pair to establish a communications link. The timeline of Figure 22 provides an overview of the procedure. The first part of initialization is the Handshake procedure which is specified in Recommendation G.994.1.

ATU-C

Handshake (see Rec. G.994.1)	Transceiver training (see 11.7)	Channel analysis (see 11.9)	Exchange (see 11.11)
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ATU-R

Handshake (see Rec. G.994.1)	Transceiver training (see 11.8)	Channel analysis (see 11.10)	Exchange (see 11.12)
---------------------------------	------------------------------------	---------------------------------	-------------------------

time→

Figure 22/G.992.2 – Overview of initialization



In subsequent parts of the initialization, in order to maximize the throughput and reliability of this link, ADSL transceivers shall determine certain relevant attributes of the connecting channel and establish transmission and processing characteristics suitable to that channel. During initialization each receiver can determine the relevant attributes of the channel through the transceiver training and channel analysis procedures. Certain processing and transmission characteristics can also be established at each receiver during this time. During the exchange process each receiver shares with its corresponding far-end transmitter certain transmission settings that it expects to see. Specifically, each receiver communicates to its far-end transmitter the number of bits and relative power levels to be used on each DMT subcarrier, as well as any messages and final data rates information. For highest performance these settings should be based on the results obtained through the transceiver training and channel analysis procedures.

Determination of channel attribute values and establishment of transmission characteristics requires that each transceiver produces, and appropriately responds to, a specific set of precisely-timed signals. This subclause describes these initialization signals, along with the rules that determine the proper starting and ending time for each signal. This description is made through the definition of initialization signalling states in which each transceiver will reside, and the definition of initialization signals that each transceiver will generate. A state and the signal generated while in that state have the same name, which may sometimes, for clarity, be prefixed by "state" or "signal".

The sequence of generated downstream and upstream states/signals for a successful initialization procedure is shown by the time-lines of Figures 24 to 26. Details of the timing of the states are shown in Figure 27. The dashed arrows indicate that the change of state in the ATU at the head of the arrow is caused by a successful reception of the last signal shown in the box at the base of the arrow. For example, in Figure 25, the ATU-R stays in state R-REVERB3 until it finishes receiving C-CRC2, at which point it moves on to R-SEGUE2 after an appropriate delay (see 11.10.2).

NOTE – The figures show the sequence of events in a successful initialization.

The description of a signal will consist of three parts:

- 1) The first part is a description of the voltage waveform that the transmitter shall produce at its output when in the corresponding state. The output voltage waveform of a given initialization signal is described using the DMT transmitter reference model shown in Figure 2.
- 2) The second is a statement of the required duration, expressed in DMT symbol periods, of the signal. This signal duration may be a constant or may depend upon the detected signalling state of the far-end transceiver. The duration of a single DMT symbol period depends on whether the cyclic prefix is being used; some initialization signals contain a cyclic prefix, and some do not. ATU-C signals up to and including C-SEGUE1 are transmitted without a cyclic prefix; those from C-RATES1 on are transmitted with a prefix. Similarly, ATU-R signals up to and including R-SEGUE1 do not use a prefix; those from R-REVERB3 onward do. The duration of any signal in seconds is therefore the defined number of DMT symbol periods times the duration of the DMT symbol being used.
- 3) The third part of a signal's description is a statement of the rule specifying the next state.

### **11.1.2 Transparency to methods of separating upstream and downstream signals**

Manufacturers may choose to implement this Recommendation using either non-overlapped spectrum mode (Annex A), or overlapped spectrum mode (Annex B). The initialization procedure described here ensures compatibility between these different implementations by specifying all upstream and downstream control signals to be in the appropriate, but narrower, frequency bands that would be used by a non-overlapped transceiver, and by defining a time period during which an overlapped spectrum transceiver can train its echo canceller.

### 11.1.3 Initialization Reset Procedure

If errors or malfunctions are detected or timeout limits are exceeded at various points in the initialization sequence, an Initialization Reset Procedure shall be executed. An ATU executes an Initialization Reset Procedure by transitioning to Recommendation G.994.1. An ATU-R invoking the Initialization Reset Procedure shall transition to R-SILENT0. An ATU-C invoking the Initialization Reset Procedure shall transition to C-SILENT1.

If errors occur during SHOWTIME, an Initialization Reset Procedure may also be invoked.

## 11.2 Handshake – ATU-C

The detailed procedures for handshake at the ATU-C are defined in Recommendation G.994.1. An ATU-C, after power-up, loss of signal, recovery from errors during the initialization procedure, Fast Retrain request abort, Fast Retrain truncate, Fast Retrain unknown profile, events that trigger power management transitions requiring the initialization procedure or optional self test, shall enter the initial G.994.1 state C-SILENT1. The ATU-C may transition to the Initialization Reset Procedure under instruction from the network. From either state, operation shall proceed according to the procedures defined in Recommendation G.994.1.

If the G.994.1 procedures select this Recommendation as the mode of operation, the ATU-C shall transition to state C-QUIET2 at the conclusion of G.994.1 operation.

If the G.994.1 procedures select "Escape to Fast Retrain" as the mode of operation, the ATU-C shall transition to state C-QUIET-EF1 at the conclusion of G.994.1 operation.

An ATU-C wishing to indicate G.992.2 capabilities during in a G.994.1 CL message shall do so by setting to 1<sub>b</sub> at least one of the Level 1 {SPar(1)} G.992.2 bits as defined in Table 11/G.994.1. For each Level 1 {SPar(1)} bit for G.992.2 set to 1<sub>b</sub>, a corresponding {NPar(2)} field shall also be present. The {NPar(2)} field corresponding to the "G.992.2 – A/B" Level 1 bit is defined in Table 11-g/G.994.1. The {NPar(2)} field corresponding to the "G.992.2 – Annex C" Level 1 bit is defined in Table 11-i/G.994.1. The Level 2 bits have the following definitions in a CL message:

R-ACK1	Always set to 1 <sub>b</sub> in a CL message. Signifies that the ATU-C is capable of sending C-PILOT1A, C-QUIET3A, C-PILOT2 and C-QUIET5 during transceiver training.
R-ACK2	Always set to 1 <sub>b</sub> in a CL message. Signifies that the ATU-C is capable of sending C-PILOT1, C-PILOT2 and C-PILOT3 during transceiver training.
RS16	Set to 1 <sub>b</sub> if the ATU-C transmitter and receiver have the capability to use Reed-Solomon parameters R = 16 and S = 16.
Fast Retrain	Always set to 1 <sub>b</sub> in a CL message.
EOC Clear OAM	If set to 1 <sub>b</sub> , signifies that the ATU-C supports transmission and reception of G.997.1 OAM frames.
DBM	If set to 0 <sub>b</sub> , this bit shall indicate Bitmap-NR and Bitmap-NC are enabled (Dual Bitmap mode) and are used to transmit data. If set to 1 <sub>b</sub> , this bit shall indicate Bitmap-NR and Bitmap-NC are disabled (FEXT Bitmap mode), i.e. only Bitmap-FR and Bitmap-FC are used to transmit data by ATU-C and ATU-R respectively. This mode selection shall be only performed by the ATU-C. If it is set to 1 <sub>b</sub> in a CL message, it must be set to 1 <sub>b</sub> in subsequent MS messages from either the ATU-C or ATU-R.

An ATU-C selecting a G.992.2 mode of operation in a G.994.1 MS message shall do so by setting to 1<sub>b</sub> the appropriate of the Level 1 {SPar(1)} G.992.2 bit as defined in Table 11/G.994.1. For each level 1 {SPar(1)} bit for G.992.2 set to 1<sub>b</sub>, a corresponding {Npar(2)} field shall also be present. The {NPar(2)} field corresponding to this bit, as defined in Table 11-h/G.994.1 or Table 11-i/G.994.1, shall also be present in the message. The Level 2 bits have the following definitions in an MS message from the ATU-C:

R-ACK1	Signifies that the ATU-C shall send C-PILOT1A, C-QUIET3A, C-PILOT2 and C-QUIET5 during transceiver training.
R-ACK2	Signifies that the ATU-C shall send C-PILOT1, C-PILOT2 and C-PILOT3 during transceiver training.
RS16	Set to 1 <sub>b</sub> if and only if RS16 was set to 1 <sub>b</sub> in both the last previous CL message and the last previous CLR message. It signifies the capability to use Reed-Solomon parameters R = 16 and S = 16 is available in both the upstream and downstream direction.
Fast Retrain	Signifies that the ATU-C requires the ATU-R to start an escape to Fast Retrain procedure.
EOC Clear OAM	Set to 1 <sub>b</sub> , if and only this bit was set to 1 <sub>b</sub> in both the last previous CL message and the last previous CLR message. Signifies that both ATU-C and ATU-R may transmit and receive G.997.1 OAM frames.
DBM	If set to 0 <sub>b</sub> , this bit shall indicate Bitmap-NR and Bitmap-NC are enabled (Dual Bitmap mode) and are used to transmit data. If set to 1 <sub>b</sub> , this bit shall indicate Bitmap-NR and Bitmap-NC are disabled (FEXT Bitmap mode), i.e. only Bitmap-FR and Bitmap-FC are used to transmit data by ATU-C and ATU-R respectively. This mode selection shall be only performed by ATU-C. This bit shall be set to 1 <sub>b</sub> if it was set to 1 <sub>b</sub> in a previous CL message.

One and only one of the bits R-ACK1 and R-ACK2 shall be set to 1<sub>b</sub> in an MS message sent from the ATU-C. If both bits are enabled in the CL and CLR message, the R-ACK1 or R-ACK2 selection is at the ATU-C's discretion.

### 11.3 Handshake – ATU-R

The detailed procedures for handshake at the ATU-R are defined in Recommendation G.994.1. An ATU-R, after power-up, loss of signal, errors during the initialization procedure, fast retrain request abort, fast retrain truncate, fast retrain unknown profile, events that trigger power management transitions requiring the initialization procedure, or optional self test, shall enter the initial G.994.1 state R-SILENT0. Upon command from the host controller, the ATU-R shall initiate handshaking by invoking the Initialization Reset Procedure. Operation shall then proceed according to the procedures defined in Recommendation G.994.1.

If the G.994.1 procedures select this Recommendation as the mode of operation, the ATU-R shall transition to state R-QUIET2 at the conclusion of G.994.1 operation.

If the G.994.1 procedures select "Escape to Fast Retrain" as the mode of operation, the ATU-R shall transition to state R-QUIET-EF1 at the conclusion of G.994.1 operation.

An ATU-R wishing to indicate G.992.2 capabilities in a G.994.1 CLR message shall do so by setting to 1<sub>b</sub> at least one of the Level 1 {SPar(1)} G.992.2 bits as defined in Table 11/G.994.1. For each Level 1 {SPar(1)} bit for G.992.2 set to ONE, a corresponding {NPar(2)} field shall also be present. The {NPar(2)} field corresponding to the "G.992.2 – A/B" Level 1 bit is defined in Table 11-g/G.994.1. The {NPar(2)} field corresponding to the "G.992.2 – Annex C" Level 1 bit is defined in Table 11-i/G.994.1. The Level 2 bits have the following definitions in a CLR message:

**R-ACK1** Signifies that the ATU-R is capable of interworking with ATU-Cs which send C-PILOT1A, C-QUIET3A, C-PILOT2, and C-QUIET5 during transceiver training (see 11.7.3, 11.7.4, 11.7.6 and 11.7.9).

**R-ACK2** Signifies that the ATU-R is capable of interworking with ATU-Cs which send C-PILOT1, C-PILOT2, and C-PILOT3 during transceiver training (see 11.7.2, 11.7.6 and 11.7.10).

**RS16** Set to 1<sub>b</sub> if the ATU-R transmitter and receiver has the capability to use Reed-Solomon parameters R = 16 and S = 16.

**Fast Retrain** Always set to 1<sub>b</sub> in a CLR message.

**EOC Clear OAM** If set to 1<sub>b</sub>, signifies that the ATU-R support transmission and reception of G.997.1 OAM frames.

**DBM** This bit shall echo the setting of the CL message, or this bit shall be ignored.

Either R-ACK2, R-ACK1, or both shall be set to 1<sub>b</sub> in a CLR message.

An ATU-R selecting a G.992.2 mode of operation in a G.994.1 MS message shall do so by setting to 1<sub>b</sub> the appropriate of the Level 1 {SPar(1)} G.992.2 bit as defined in Table 11/G.994.1. For each Level 1 {SPar(1)} bit for G.992.2 set to 1<sub>b</sub>, a corresponding {NPar(2)} field shall also be present. The {NPar(2)} field corresponding to this bit, as defined in Table 11-g/G.994.1 or Table 11-i/G.994.1, shall also be present in the message. The Level 2 bits have the following definitions in an MS message from the ATU-R:

**R-ACK1** Signifies that the ATU-R requires the ATU-C to send C-PILOT1A, C-QUIET3A, C-PILOT2, and C-QUIET5 during transceiver training (see 11.7.3, 11.7.1, 11.7.6 and 11.7.9)

**R-ACK2** Signifies that the ATU-R requires the ATU-C to send C-PILOT1, C-PILOT2, and C-PILOT3 during transceiver training (see 11.7.2, 11.7.6 and 11.7.10).

**RS16** Set to 1<sub>b</sub> if and only if RS16 was set to 1<sub>b</sub> in both the last previous CL message and the last previous CLR message. It signifies that the capability to use Reed-Solomon parameters R = 16 and S = 16 is available in both the upstream and downstream directions.

**Fast Retrain** Signifies that the ATU-R requires the ATU-C to start an escape to fast retrain.

**EOC Clear OAM** Set 1<sub>b</sub> if and only if this bit was set to 1<sub>b</sub> in both the last previous CL message and the last previous CLR message. Signifies that both the ATU-C and ATU-R may transmit and receive G.997.1. OAM frames.

**DBM** If set to 0<sub>b</sub>, this bit shall indicate that Bitmap-NR and Bitmap-NC are enabled (Dual Bitmap mode) and are used to transmit data. If set to 1<sub>b</sub>, this bit shall indicate that Bitmap-NR and Bitmap-NC are disabled (FEXT Bitmap mode), i.e. only Bitmap-FR and Bitmap-FC are used to transmit data by ATU-C and ATU-R respectively. This mode selection shall be only performed by ATU-C. This bit shall be set to 1<sub>b</sub> if it was set to 1<sub>b</sub> in a previous CL message.

One and only one of the bits R-ACK1 or R-ACK2 shall be set to 1<sub>b</sub> in an MS message sent from the ATU-R. If both bits are enabled in the CL and CLR message, the R-ACK1 or R-ACK2 selection is at the ATU-R's discretion.

#### 11.4 Handshake power levels

When Recommendation G.994.1 (Handshake) is invoked outside of a G.992.2 session or in order to change modes of operation, the PSD levels at the ATU-R and ATU-C shall be as specified in Recommendation G.994.1. When Handshake is invoked from the procedures described in this Recommendation, the power levels shall be as specified in Table 24.

**Table 24/G.992.2 -- Handshake power levels**

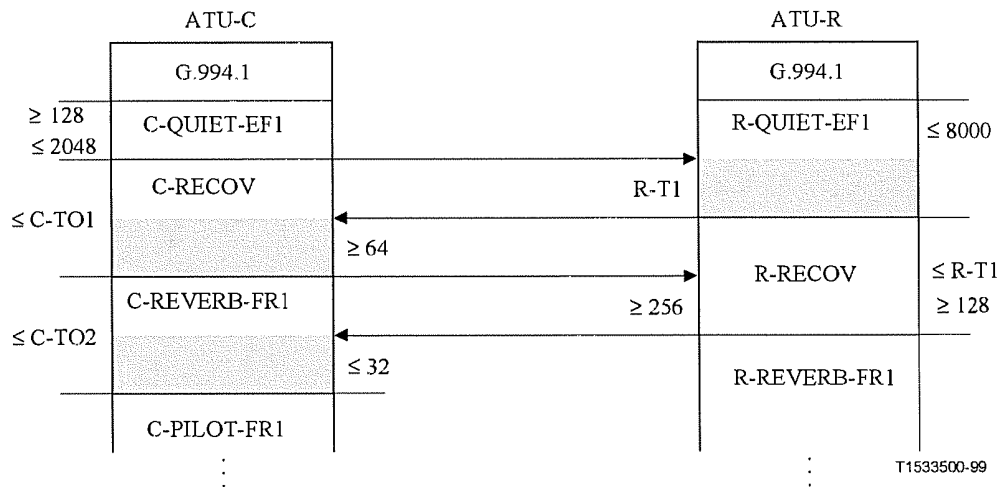
Prior G.992.2 state	ATU-C power level (dBm/Hz)	ATU-R power level (dBm/Hz)
Fast Retrain Request Abort	Nominal	Nominal
Fast Retrain Truncate	– 40 – Absolute Downstream Fast Retrain Power Cutback	– 38 – Absolute Upstream Fast Retrain Power Cutback
Fast Retrain Unknown Profile	– 40 – Absolute Downstream Fast Retrain Power Cutback	– 38 – Absolute Upstream Fast Retrain Power Cutback
Initialization Reset Procedure from errors, malfunctions or timeouts	Nominal	Nominal
L3 to L0 Power Management Transition T3a	Nominal	Nominal
L0 to L0 Power Management Transition T0a or t0c	Nominal	Nominal
L1 to L0 Power Management Transition T1a or T1c	Nominal	Nominal

#### 11.5 Escape from Handshake to Fast Retrain

If the escape to Fast Retrain mode is selected during the G.994.1 procedure, the ATUs shall perform a Fast Retrain instead of entering the Transceiver Training phase.

It is recommended that, in cases other than when the Handshake procedure has been initiated from a Fast Retrain Truncate or Fast Retrain Unknown Profile, the Handshake procedure request an escape to Fast Retrain (see Figure 23).





**Figure 23/G.992.2 – Timing diagram of escape to Fast Retrain**

### 11.5.1 C-QUIET-EF1

C-QUIET-EF1 begins at the termination of Recommendation G.994.1. The minimum duration of C-QUIET-EF1 is 128 symbols. The maximum duration of C-QUIET-EF1 is 2048 symbols.

### 11.5.2 R-QUIET-EF1

R-QUIET-EF1 begins at the termination of Recommendation G.994.1. The minimum duration of R-QUIET-EF1 is 128 DMT symbols after the detection of C-RECOV. The ATU-R shall progress to R-RECOV only after it has detected any part of the C-RECOV signal that is needed for reliable detection. The maximum duration of R-QUIET-EF1 is 8000 symbols.

## 11.6 Power levels in Transceiver Training, Channel Analysis and Exchange

All ATU-R signals defined in Transceiver Training, Channel Analysis and Exchange except R-ECT, shall be transmitted using the PSD level of the previous G.994.1 session with one exception: if Recommendation G.994.1 was invoked outside of a G.992.2 session or in order to change modes of operation, all ATU-R signals defined in Transceiver Training, Channel Analysis and Exchange except R-ECT shall be transmitted at Nominal PSD level.

C-PILOT1 and C-PILOT1A shall be transmitted using the PSD level of the previous G.994.1 session with one exception: if G.994.1 was invoked outside of a Recommendation G.992.2 session or in order to change modes of operation C-PILOT1 and C-PILOT1A shall be transmitted at Nominal PSD level. C-REVERB1 and subsequent ATU-C signals defined Transceiver Training, Channel Analysis and Exchange, unless otherwise noted, shall be transmitted at the PSD level calculated as defined in 11.7.5.

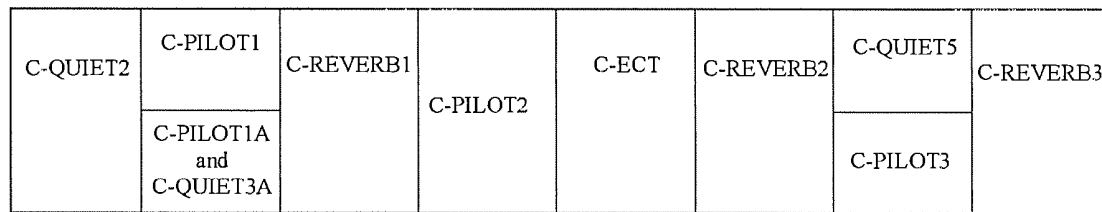
C/R-QUIET signals are defined as zero output voltage from the DAC of Figure 2.

Because C-ECT and R-ECT are vendor-defined signals, the above PSD specification shall only be interpreted as a maximum.

## 11.7 Transceiver training – ATU-C

This subclause and subclause 11.8 describe the signals transmitted during transceiver training by the ATU-C and ATU-R, respectively (see Figure 24). Synchronization of the mutual training begins with the transmission of R-REVERB1 (see 11.8.2) and is maintained throughout training by both transceivers counting the number of symbols from that point on.

ATU-C



ATU-R



Time →

T1533510-99

NOTE – Because the ATU-C and ATU-R states are synchronized from this point on, no more "cause-and-effect arrows are shown.

**Figure 24/G.992.2 – Timing diagram of transceiver training (see 11.7-11.8)**

### 11.7.1 C-QUIET2

C-QUIET2 begins after termination of Recommendation G.994.1. The minimum duration of C-QUIET2 is 128 symbols. The maximum duration of C-QUIET2 is 2048 symbols.

The state that the ATU-C enters following C-QUIET2 depends upon parameters negotiated in the G.994.1 procedure.

### 11.7.2 C-PILOT1

During C-PILOT1 or C-PILOT1A as appropriate, the ATU-C shall measure the aggregate received upstream power on subcarriers 7-18 of R-REVERB1, and thereby calculate a downstream PSD.

Within 16 symbols after detection of the first symbol of R-REVERB1 the ATU-C shall start a timer. This establishes synchronization of the subsequent transitions between states at ATU-C and ATU-R. After 512 symbols, as measured by this timer, the ATU-C shall go to C-REVERB1. Thus the minimum duration of C-PILOT1 is 512 symbols, but it will exceed this by the round-trip propagation and signal-processing time plus the amount of time required by ATU-R to detect C-PILOT1 and respond by transmitting R-REVERB1 (see 11.8.2).

C-REVERB1 follows C-PILOT1.

C-PILOT1 is a single frequency sinusoid at 276 kHz defined as:

$$X_k = \begin{cases} 0 & \text{for } k \neq 64, 0 \leq k \leq 127 \\ A_{C-PILOT1} & \text{for } k = 64 \end{cases}$$

$A_{C-PILOT1}$  shall be such that PSD level is as defined in 11.6. The duration of C-PILOT1 can be up to 4436 symbols

C-REVERB1 follows C-PILOT1.

### 11.7.3 C-PILOT1A

C-PILOT1A is the same transmitted signal as C-PILOT1. The duration of C-PILOT1A can be up to 4000 symbols. The exact duration of C-PILOT1A depends upon the duration of R-QUIET2.

Within 16 symbols after detection of the first symbol of R-REVERB1 the ATU-C shall start a timer (this establishes synchronization of the subsequent transitions between states at the ATU-C and ATU-R) and shall proceed to C-QUIET3A.

C-QUIET3A follows C-PILOT1A.

#### 11.7.4 C-QUIET3A

Within 512 to 516 symbols after detection of the first symbol of R-REVERB1, the ATU-C shall go to C-REVERB1. Thus, the minimum duration of C-QUIET3A is 512-16 (496) symbols; the maximum is 516 symbols. The total duration of C-QUIET3A and C-PILOT1A is a minimum of 512 symbols, but it will exceed this (up to a maximum duration of 4436 symbols) by the round-trip propagation and signal processing time plus the amount of time required by ATU-R to detect C-PILOT1A and respond by transmitting R-REVERB1.

C-REVERB1 follows C-QUIET3A.

#### 11.7.5 C-REVERB1

C-REVERB1 is a signal that allows the ATU-C and ATU-R receiver to adjust its automatic gain control (AGC) to an appropriate level.

The C-REVERB1 signal shall modulate a contiguous range of subcarriers from  $n$  to  $m$ , where  $n \leq 37$  and  $m \geq 68$ . Subsequent C-REVERB and C-SEGUE signals shall use the same range of subcarriers as C-REVERB1. The value of  $n$  and  $m$  are CO vendor discretionary. All ATU-R receivers, during Initialization, shall tolerate the maximum number of subcarriers allowed by the overlapped spectrum mask defined in Annex B.

The data pattern used in C-REVERB1 shall be the pseudo-random downstream sequence DPRD,  $d_n$  for  $n = 1$  to  $2 \times N_{SC-DN}$  and encoding method defined in 7.10.3.

The bits shall be used as follows: The first pair of bits ( $d_1$  and  $d_2$ ) are used for the dc and Nyquist subcarriers (the power assigned to them is, of course, zero, so the bits are effectively ignored); then the first and second bits of subsequent pairs are used to define the  $X_i$  and  $Y_i$  for  $i = 1$  to  $N_{SC-DN} - 1$  as defined in Table 9.

The period of PRD is 511 bits. The bits  $d_1$  to  $d_9$  shall be re-initialized for each symbol, so each symbol of C-REVERB1 is identical. Bits 129 and 130, which modulate the pilot carrier, shall be overwritten by  $\{0,0\}$  generating the  $\{+,+\}$  constellation.

The transmit PSD for C-REVERB1 shall be the Reference PSD level of  $(-40 - 2n)$  dBm/Hz, with  $2n$  = the maximum of either the Absolute Downstream Fast Retrain Power Cutback or the Initialization Politeness Power Cutback. The Initialization Politeness Power Cutback is obtained using Table 25, based on the average upstream loop attenuation measured during R-REVERB1. This reference PSD level shall become the reference level for all subsequent gain calculations. The average upstream loop attenuation is defined as the difference between the upstream reference power in dBm and the total upstream power measured on subcarriers 7 through 18 during R-REVERB1. The upstream reference power is defined as the total transmit power on subcarriers 7 through 18, using the R-REVERB1 reference transmit PSD level.

**Table 25/G.992.2 – Initialization Politeness Power Cutback: Downstream PSD as a function of average upstream loop attenuation**

Average upstream loop attenuation (dB)	>6	>5	>4	>3	>2	>1	>0
Initialization Politeness Power Cutback (dB)	0	2	4	6	8	10	12

The duration of C-REVERB1 is 512 (repeating) symbols without cyclic prefix. C-PILOT2 follows C-REVERB1.

The C-REVERB1 signal should be sufficiently wideband in order to probe the transmission channel in such a way that the C-REVERB1 signal does not sufficiently lengthen the estimated channel impulse response as measured using C-REVERB1.

#### **11.7.6 C-PILOT2**

The C-PILOT2 signal is the same as C-PILOT1; the duration is 3072 symbols. C-ECT follows C-PILOT2.

#### **11.7.7 C-ECT**

C-ECT is a vendor-defined signal that is used to train the echo canceller at ATU-C for EC implementations. Vendors of FDM and EC versions have complete freedom to define their C-ECT signal given the power constraints defined in Annexes A and B. The duration of C-ECT, however, is fixed at 512 symbols. The receiver at ATU-R should ignore this signal. C-REVERB2 follows C-ECT.

#### **11.7.8 C-REVERB2**

C-REVERB2 is a signal that allows the ATU-R receiver to perform synchronization and to train any receiver equalizer. C-REVERB2 is the same as C-REVERB1 (see 11.7.5). The duration of C-REVERB2 is 1536 (repeating) symbols without cyclic prefix. The state following C-REVERB2 depends upon negotiated parameters in the G.994.1 procedure.

#### **11.7.9 C-QUIET5**

The duration of C-QUIET5 is 512 symbols. C-REVERB3 follows C-QUIET5.

#### **11.7.10 C-PILOT3**

C-PILOT3 signal is the same as C-PILOT1 (see 11.7.2). The duration of C-PILOT3 is 512 symbols. C-REVERB3 follows C-PILOT3.

#### **11.7.11 C-REVERB3**

C-REVERB3 is a second training signal, which allows the ATU-R receiver to perform or maintain synchronization and to further train any receiver equalizer. C-REVERB3 is the same as C-REVERB2 (see 11.7.8). The duration of C-REVERB3 is 1024 (repeating) symbols without cyclic prefix. This is the last segment of transceiver training. C-SEGUE1 follows immediately.

### **11.8 Transceiver training – ATU-R**

#### **11.8.1 R-QUIET2**

R-QUIET2 begins after termination of Recommendation G.994.1. The minimum duration of R-QUIET2 is 128 DMT symbols after the detection of C-PILOT1/1A. The ATU-R shall progress to R-REVERB1 only after it has detected any part of the following C-QUIET3A or C-PILOT1/1A that is needed for reliable detection. The maximum duration of R-QUIET2 is 8000 symbols.

Loop timing is defined as the combination of the slaving of an ADC clock to the received signal (i.e. to the other transceiver's DAC clock), and tying the local DAC and ADC clocks together. Loop timing shall always be performed at the ATU-R and be acquired while transmitting R-QUIET2 and before the last 512 symbols of R-REVERB1. An ATU-C may train its equalizer during the last 512 symbols of R-REVERB1. Such equalizer training, at the ATU-C, requires sufficient sampling clock stability at the ATU-R transmitter. After loop timing is acquired at the ATU-R, the ATU-R shall re-acquire loop timing after a period with free running timing (i.e. no C-PILOT over maximum

512 symbols) within 512 symbols after the C-PILOT re-appearing. This applies to C-QUIET5 and may also apply to C-QUIET3A and C-ECT.

NOTE – The delay in the ATU-R in going from C-QUIET2 to R-REVERB1 is to allow the possibility that the ATU-R may fully synchronize its time base before sending R-REVERB1.

### **11.8.2 R-REVERB1**

R-REVERB1 is used to allow the ATU-C to:

- 1) measure the upstream wideband power in order to adjust the ATU-C transmit power level;
- 2) adjust its receiver gain control;
- 3) synchronize its receiver and train its equalizer.

The data pattern used in R-REVERB1 is UPRD defined in 7.10.4.

R-REVERB1 is a periodic signal, without cyclic prefix, that is transmitted consecutively for 4096 symbols. The first 512 symbols coincide with C-QUIET3A or C-PILOT1 signal in time, the second 512 symbols coincide with C-REVERB1, and the last 3072 symbols coincide with C-PILOT2. R-QUIET3 immediately follows R-REVERB1.

### **11.8.3 R-QUIET3**

The duration of R-QUIET3 is 2048 symbols, of which the first 512 symbols coincide with C-ECT in time, and the next 1536 symbols coincide with C-REVERB2. The final symbol of R-QUIET3 may be shortened by any number of samples to accommodate transmitter to receiver frame alignment. R-ECT immediately follows R-QUIET3.

### **11.8.4 R-ECT**

R-ECT, similar to C-ECT, is a vendor-defined signal that may be used to train an echo canceller at the ATU-R. Vendors of FDM and EC versions have absolute freedom to define R-ECT signal given the power constraints defined in Annexes A and B. The duration of R-ECT is however, fixed at 512 DMT symbols. The receiver at the ATU-C ignores this signal. R-REVERB2 follows R-ECT.

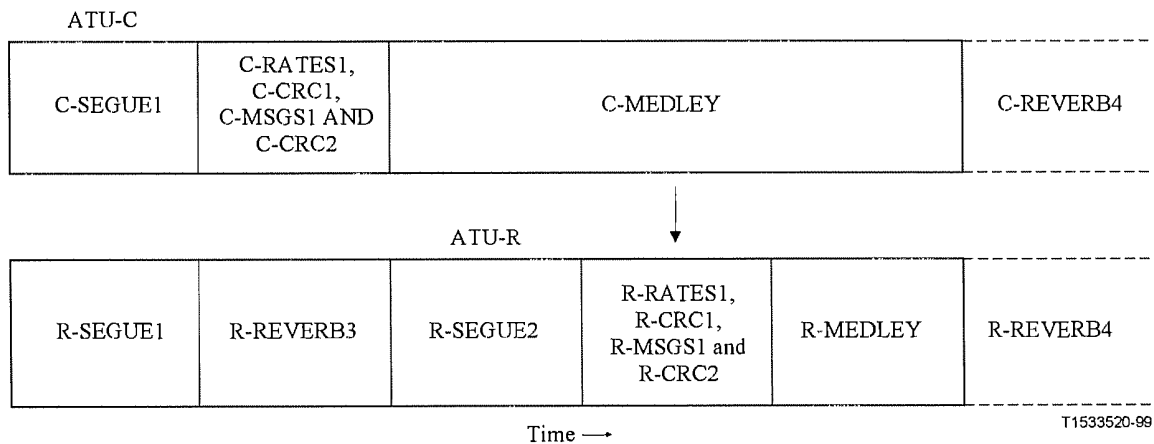
### **11.8.5 R-REVERB2**

The signal R-REVERB2 is the same as R-REVERB1 (see 11.8.2); it can be used by ATU-C to perform timing recovery and receiver equalizer training. The duration of R-REVERB2 shall be between 1024 and 1056 symbols. This signal is the last segment of transceiver training. ATU-R then begins channel analysis and starts transmitting R-SEGUE1.



### 11.9 Channel analysis (ATU-C)

See Figure 25.



**Figure 25/G.992.2 – Timing diagram of channel analysis (see 11.7-11.8)**

During channel analysis the synchronization between ATU-C and ATU-R may be broken during R-REVERB3, which has an indefinite duration; this potential timeout is described in 11.10.2. Furthermore, if during channel analysis any crc check sum indicates an error in any of the control data, this shall invoke the Initialization Reset Procedure.

#### 11.9.1 C-SEGUE1

Except for the pilot tone, C-SEGUE1 shall be generated from a tone-by-tone 180-degree phase reversal of C-REVERB1 (i.e. + maps to –, and – maps to +, for each of the 4-QAM signal constellation). The duration of C-SEGUE1 is ten (repeating) symbol periods. Following C-SEGUE1, ATU-C enters state C-RATES1.

#### 11.9.2 C-RATES1

C-RATES1 is the first ATU-C signal for which a cyclic prefix (defined in 7.11) is used. The purpose of C-RATES1 is to transmit four options for data rates and formats to the ATU-R. Each option consists of three fields:

- The  $B_F$  field is not applicable to this Recommendation.  $B_F$  contains a total of 80 bits organized as 10 entries each of eight bits. All bits shall be set to  $0_b$ .
- The  $B_I$  field contains the number of bytes in a DF allocated to the AS0 (downstream) and LS0 (upstream) channel.  $B_I$  contains a total of 80 bits organized as 10 entries each of eight bits. The first entry in  $B_I$  contains the number of bytes in a DF allocated to AS0. The eighth entry in  $B_I$  contains the number of bytes in a DF allocated to LS0. All other bits in  $B_I$  shall be set to  $0_b$ .
- The RRSI field contains Reed-Solomon FEC and interleaver parameters. The RRSI field contains a total of 80 bits organized as 10 entries each of eight bits. The second entry in the RRSI field contains the parameter  $RS_I$ : The number of parity bytes per symbol in the downstream transmission direction with  $RS_I$  equal to R/S. The third entry in the RRSI field contains the parameter S: S is the number of DFs per Reed-Solomon codeword in the downstream transmission direction. The fourth entry contains the parameter I: The downstream interleave depth in codewords. The seventh entry in the RRSI field contains the

parameter  $RS_I$ : The number of parity bytes per symbol in the upstream transmission direction with  $RS_I$  equal to  $R/S$ . The eighth entry in the RRSI field contains the parameter  $S$ ;  $S$  is the number of DFs per Reed-Solomon codeword in the upstream transmission direction. The ninth entry contains the parameter  $I$ : The upstream interleave depth in codewords. All other bits in RRSI shall be set to  $0_b$ .

The four options are transmitted in order of decreasing preference. C-RATES1 is preceded by a 4-byte prefix of  $\{55\ 55\ 55\ 55\}_{16}$ . Table 26 summarizes C-RATES1 and Table 27 summarizes RRSI fields of C-RATES1.

**Table 26/G.992.2 – C-RATES1 message**

	Prefix	Option 1			Option 2			Option 3			Option 4		
		$B_F$	$B_I$	RRSI	$B_F$	$B_I$	RRSI	$B_F$	$B_I$	RRSI	$B_F$	$B_I$	RRSI
Number of bytes	4	10	10	10	10	10	10	10	10	10	10	10	10

**Table 27/G.992.2 – RRSI fields of C-RATES1**

Entry #	Field		<-----bits----->							
			7	6	5	4	3	2	1	0
1	$RS_F$	Downstream	N/A to Recommendation G.992.2 – set to $\{00000000_b\}$							
2	$R$		$0_b$	$0_b$	value of $R$ [MSB $\leftrightarrow$ LSB]					
3	$S$		$0_b$	$0_b$	value of $S$ [MSB $\leftrightarrow$ LSB]					
4	$I$		$I_7$	$I_6$	$I_5$	$I_4$	$I_3$	$I_2$	$I_1$	$I_0$
5	$FS(LS2)$	Upstream	N/A to Recommendation G.992.2 – set to $\{00000000_b\}$							
6	$RS_F$		N/A to Recommendation G.992.2 – set to $\{00000000_b\}$							
7	$R$		$0_b$	$0_b$	value of $R$ [MSB $\leftrightarrow$ LSB]					
8	$S$		$0_b$	$0_b$	value of $S$ [MSB $\leftrightarrow$ LSB]					
9	$I$		$I_7$	$I_6$	$I_5$	$I_4$	$I_3$	$I_2$	$I_1$	$I_0$
10	$FS(LS2)$		N/A to Recommendation G.992.2 – set to $\{00000000_b\}$							

Only one bit of information is transmitted in each symbol of C-RATES1: A zero bit is encoded to one symbol of C-REVERB1 and a one bit is encoded to one symbol of C-SEGUE1. Since there are a total of 992 bits of C-RATES1 information, the duration of C-RATES1 is 992 symbols. The 992 bits are to be transmitted in the order shown in Table 26 with the least significant bit first. That is, the least significant bit of option 1,  $B_F$ , is to be transmitted during the 33rd symbol of C-RATES1, after the prefix. Following C-RATES1, the ATU-C shall enter state C-CRC1.

### 11.9.3 C-CRC1

C-CRC1 is a cyclic redundancy check for detection of errors in the reception of C-RATES1 at the ATU-R. The crc bits are computed from the C-RATES1 bits using the equation:

$$c(D) = a(D) D^{16} \text{ modulo } g(D),$$

where:

$$a(D) = a_0 D^{959} + a_1 D^{958} \dots + a^{959}$$

is the message polynomial formed from the 960 bits of C-RATES1, with  $a_0$  the least significant bit of the first byte of C-RATES1 (i.e. option 1 B<sub>F</sub>);

$$g(D) = D^{16} + D^{12} + D^5 + 1$$

is the crc generator polynomial, and

$$c(D) = c_0 D^{15} + c_1 D^{14} \dots + c_{14} D + c_{15}$$

is the crc check polynomial.

The 16 bits  $c_0$ - $c_{15}$  are transmitted ( $c_0$  first and  $c_{15}$  last) in 16 symbol periods using the method described in 11.9.2. Following C-CRC1, the ATU-C shall enter state C-MSG1.

### 11.9.4 C-MSG1

C-MSG1 transmits a 48-bit message signal to the ATU-R. This message includes ATU-C transmit power level used, echo canceller option, etc. The message,  $m$ , is defined by:

$$m = \{m_{47}, m_{46}, \dots, m_1, m_0\}$$

with  $m_0$  being transmitted first. The message components are defined in the following subclauses, and their assigned positions within the composite message,  $m$ , are defined in Table 28. A total of 48 symbol periods are used to communicate the 48-bit message, using the encoding method described in 11.9.2. Following C-MSG1, the ATU-C shall enter signalling state C-CRC2.

**Table 28/G.992.2 – Assignment of 48 bits of C-MSG1**

Suffix(es) of $m_i$ (Note 1)	Parameter (Note 3)
47-44	ATU target noise margin (Note 2)
43-17	Reserved by ITU-T
16	Echo cancellation option
15	Unused (shall be set to 1 <sub>b</sub> )
14-12	Reserved by ITU-T
11	NTR
10, 9	Framing mode
8-6	Initialization Politeness Power Cutback
5, 4	Reserved by ITU-T
3, 2, 1, 0	Maximum numbers of bits per subcarrier supported
NOTE 1 – Within the separate fields the least significant bits have the lowest subscripts.	
NOTE 2 – A positive number of dB; binary coded 0-15 dB.	
NOTE 3 – All reserved bits shall be set to 0 <sub>b</sub> .	

**11.9.4.1 Minimum required SNR margin – Bits 47-44**

Binary coded 0 to 15 dB.

**11.9.4.2 Echo cancellation option – Bit 16**

$m_{16} = 0_b$  indicates no echo cancellation,  $m_{16} = 1_b$  indicates echo cancellation.

**11.9.4.3 Unused – Bit 15**

$m_{15}$  shall be set to  $1_b$ .

**11.9.4.4 NTR – Bit 11**

$m_{11} = 1_b$  indicates that the ATU-C will use indicator bits IB23 to IB20 as defined in Table 4 for the transport of the NTR.

**11.9.4.5 Framing mode – Bits 10, 9**

$m_{10}$  and  $m_9$  shall both be set to  $1_b$ .

**11.9.4.6 Initialization Politeness Power Cutback – Bits 8, 7, 6**

The ATU-C shall report the level of Initialization Politeness Power Cutback as a result of the calculation described in 11.7.5. The encoding rules for  $m_8$ ,  $m_7$ ,  $m_6$  are shown in Table 29.

**Table 29/G.992.2 – C-MSG1 encoding rules for Initialization Politeness Power Cutback (dB)**

$m_8$	$m_7$	$m_6$	Initialization Politeness Power Cutback (dB)
$1_b$	$1_b$	$1_b$	0
$1_b$	$1_b$	$0_b$	2
$1_b$	$0_b$	$1_b$	4
$1_b$	$0_b$	$0_b$	6
$0_b$	$1_b$	$1_b$	8
$0_b$	$1_b$	$0_b$	10
$0_b$	$0_b$	$1_b$	12

**11.9.4.7 Maximum numbers of bits per subcarrier supported – Bits 3-0**

The  $N_{\text{downmax}}$  (transmit) capability shall be binary encoded onto  $\{m_3 \dots m_0\}$  (e.g.  $1101_b = 13_{10}$ ). The maximum number of bits for the upstream data,  $N_{\text{upmax}}$ , that the ATU-C receiver can support need not be signalled to the ATU-R; it will be implicit in the bits and gains message, C-B&G, which is transmitted after channel analysis.

**11.9.5 C-CRC2**

C-CRC2 is a cyclic redundancy check for detection of errors in the reception of C-MSG1 at the ATU-R. The crc generator polynomial is as defined in 11.9.3. The crc message polynomial is as constructed in 11.9.3, with  $m_0$  corresponding to  $a_0$  and  $m_{47}$  corresponding to  $a_{47}$ . The crc check polynomial is generated in the same way as defined in 11.9.3. These 16 bits are transmitted in 16 symbol periods using the method described in 11.9.3. Following C-CRC2, the ATU-C shall enter signalling state C-MEDLEY.

### 11.9.6 C-MEDLEY

C-MEDLEY is a wideband pseudo-random signal used for estimation at the ATU-R of the downstream SNR. The data to be transmitted are derived from the pseudo-random sequence, PRD, and modulated as defined in 11.7.5. In contrast to C-REVERB1, however, the cyclic prefix is used and the data sequence continues from one symbol to the next (i.e.  $d_1$  to  $d_9$  are not re-initialized for each symbol); since PRD is of length 511, and 512 bits are used for each symbol, the subcarrier vector for C-MEDLEY therefore changes from one symbol period to the next. The pilot subcarrier is over-written by the (+,+) signal constellation. C-MEDLEY is transmitted for 16 384 symbol periods. Following C-MEDLEY the ATU-C shall enter the state C-REVERB4.

### 11.10 Channel analysis (ATU-R)

During channel analysis there are two situations where the ATU-R shall invoke the Initialization Reset Procedure: a timeout and a detected error in the received control data. A timeout occurs if the time in R-REVERB3 exceeds the limit of 4000 symbols. Also, if any C-CRC checksum indicates that there is an error in the received control data, then it shall invoke the Initialization Reset Procedure.

#### 11.10.1 R-SEGUE1

R-SEGUE1 is generated from a tone-by-tone 180-degree phase reversal of R-REVERB1 (i.e. + maps to −, and − maps to +, for each of the 4-QAM signal constellation). The duration of R-SEGUE1 is 10 symbol periods. Following R-SEGUE1 the ATU-R shall enter state R-REVERB3.

#### 11.10.2 R-REVERB3

R-REVERB3 is similar to R-REVERB1 (see 11.8.2); the only difference is that R-REVERB3 is the first ATU-R signal with the addition of a cyclic prefix to every symbol (defined in 7.11). The duration of R-REVERB3 is not fixed but has a maximum of 4000 symbols. If C-CRC2 is not detected within 4000 symbols, the ATU-R shall invoke the Initialization Reset Procedure. After detection of C-RATES1-C-CRC2, the ATU-R shall continue to send R-REVERB3 for 20 additional symbols before entering R-SEGUE2.

#### 11.10.3 R-SEGUE2

The signal R-SEGUE2 is similar to R-SEGUE1 (see 11.10.1). The only difference is the addition of the cyclic prefix. Following R-SEGUE2 the ATU-R shall enter state R-RATES1.

#### 11.10.4 R-RATES1

See Table 30.

**Table 30/G.992.2 – R-RATES1**

	Prefix	Option 1			Option 2			Option 3			Option 4		
		B <sub>F</sub>	B <sub>I</sub>	RRSI	B <sub>F</sub>	B <sub>I</sub>	RRSI	B <sub>F</sub>	B <sub>I</sub>	RRSI	B <sub>F</sub>	B <sub>I</sub>	RRSI
Number of bytes	4	3	3	5	3	3	5	3	3	5	3	3	5

The purpose of R-RATES1 for the upstream channel is the same as that of C-RATES1 for the downstream channel (see 11.9.2). Each option consists of three fields:

- The B<sub>F</sub> field is not applicable to this Recommendation. B<sub>F</sub> contains a total of 24 bits organized as three entries each of eight bits. All bits shall be set to 0<sub>b</sub>.



- The  $B_I$  field contains the number of bytes in a DF allocated to the LS0 (upstream) channel.  $B_I$  contains a total of 24 bits organized as three entries each of eight bits. The first entry in  $B_I$  contains the number of bytes in a DF allocated to LS0. All other bits in  $B_I$  shall be set to  $0_b$ .
- The RRSI field contains Reed-Solomon FEC and interleaver parameters. The RRSI field contains a total of 40 bits organized as five entries each of eight bits (see Table 31). The second entry in the RRSI field contains the parameter  $RS_I$ : The number of parity bytes per symbol in the upstream transmission direction with  $RS_I$  equal to  $R/S$ . The third entry in the RRSI field contains the parameter  $S$ ;  $S$  is the number of DFs per Reed-Solomon codeword in the upstream transmission direction. The fourth entry contains the parameter  $I$ : The eight least significant bits of the upstream interleave depth in codewords. All other bits in RRSI shall be set to  $0_b$ .

**Table 31/G.992.2 – RRSI fields of R-RATES1**

Entry #	Field		← bits →							
			7	6	5	4	3	2	1	0
1	$RS_F$	Upstream	N/A to Recommendation G.992.2 – set to $\{00000000_b\}$							
2	$R$		$0_b$	$0_b$	value of $R$ [MSB ↔ LSB]					
3	$S$		$0_b$	$0_b$	value of $S$ [MSB ↔ LSB]					
4	$I$		$I_7$	$I_6$	$I_5$	$I_4$	$I_3$	$I_2$	$I_1$	$I_0$
5	$FS(LS2)$		N/A to Recommendation G.992.2 – set to $\{00000000_b\}$							

The four options are transmitted in order of decreasing preference. The ATU-C has control over all the data rates, so R-RATES1 is copied from the appropriate fields of C-RATES1.

Only one bit of information is transmitted during each symbol period of R-RATES1: A zero bit is encoded to one symbol of R-REVERB1 and a one bit is encoded to one symbol of R-SEGUE1 (with addition of cyclic prefix). Since there are a total of 384 bits of RATES1 information, the length of R-RATES1 is 384 symbols. The 384 bits are to be transmitted in the order shown in Table 30, with the least significant bit first. That is, the least significant bit of option 1,  $B_F$  (see Table 30) is to be transmitted during the 33rd symbol of R-RATES1, after the prefix. Following R-RATES1, the ATU-R shall enter state R-CRC1.

#### 11.10.5 R-CRC1

R-CRC1 is a cyclic redundancy check intended for detection of an error in the reception of R-RATES1 at the ATU-C. The crc polynomial  $c(D)$  and generator polynomial  $g(D)$  are the same as for C-CRC1 (see 11.9.3). The 16 bits  $c_0$  to  $c_{15}$  are transmitted ( $c_0$  first and  $c_{15}$  last) in 16 symbol periods using the same method as R-RATES1 (see 11.10.4). Following R-CRC1, the ATU-R shall enter state R-MSG1.

#### 11.10.6 R-MSG1

R-MSG1 transmits a 48-bit message signal to the ATU-C. This message includes echo canceller option, etc. The message,  $m$ , is defined by:

$$m = \{m_{47}, m_{46}, \dots, m_1, m_0\}$$

with  $m_0$ , the least significant bit, being transmitted first. The message components are defined in the following subclauses, and their assigned positions within the composite message,  $m$ , are defined in Table 32.

A total of 48 symbol periods are used to communicate the 32-bit message, using the encoding method described in 11.10.4. Following R-MSG1, the ATU-R shall enter signalling state R-CRC2.

**Table 32/G.992.2 – Assignment of 48 bits of R-MSG1**

Suffix(es) of $m_i$ (Note 1)	Parameter (Note 2)
47-17	Reserved by ITU-T
16	Echo cancellation option
15	Unused (shall be set to 1 <sub>b</sub> )
14-12	Reserved by ITU-T
11	Network timing reference
10, 9	Framing mode
8-4	Reserved by ITU-T
3-0	Maximum numbers of bits per subcarrier supported
NOTE 1 – Within the separate fields the least significant bits have the lowest subscripts.	
NOTE 2 – All reserved bits shall be set to 0 <sub>b</sub> .	

#### 11.10.6.1 Echo cancellation option – Bit 16

$m_{16} = 0_b$  indicates no echo cancellation;  $m_{16} = 1_b$  indicates echo cancellation.

#### 11.10.6.2 Unused – Bit 15

$m_{15}$  shall be set to 1<sub>b</sub>.

#### 11.10.6.3 Framing mode – Bits 10, 9

$m_{10}$  and  $m_9$  shall both be set to 1<sub>b</sub>.

#### 11.10.6.4 Network timing reference – Bit 11

$m_{11} = 1_b$  indicates the ATU-R supports reconstruction of the network timing reference from the downstream indicator bits 23-20.

#### 11.10.6.5 Maximum numbers of bits per subcarrier supported – Bits 3-0

The  $N_{upmax}$  (transmit) capability is encoded onto  $\{m_3 \dots m_0\}$  with a conventional binary representation (e.g. 1101<sub>b</sub> = 13<sub>10</sub>).

NOTE – The maximum number of bits for the downstream data,  $N_{downmax}$ , that the ATU-R receiver can support need not be signalled to the ATU-C; it will be implicit in the bits and gains message, R-B&G, which is transmitted after channel analysis.

#### 11.10.7 R-CRC2

R-CRC2 is a cyclic redundancy check for detection of errors in the reception of R-MSG1 at the ATU-C. The crc generator polynomial is as defined in 11.10.5. The crc message polynomial is as constructed in 11.10.5, with  $m_0$  corresponding to  $a_0$  and  $m_{47}$  corresponding to  $a_{47}$ . The crc check polynomial is generated in exactly the same way as described in 11.10.5. These 16 bits are

transmitted in 16 symbol periods using the method described in 11.10.5. Following R-CRC2, the ATU-R shall enter state R-MEDLEY.

#### **11.10.8 R-MEDLEY**

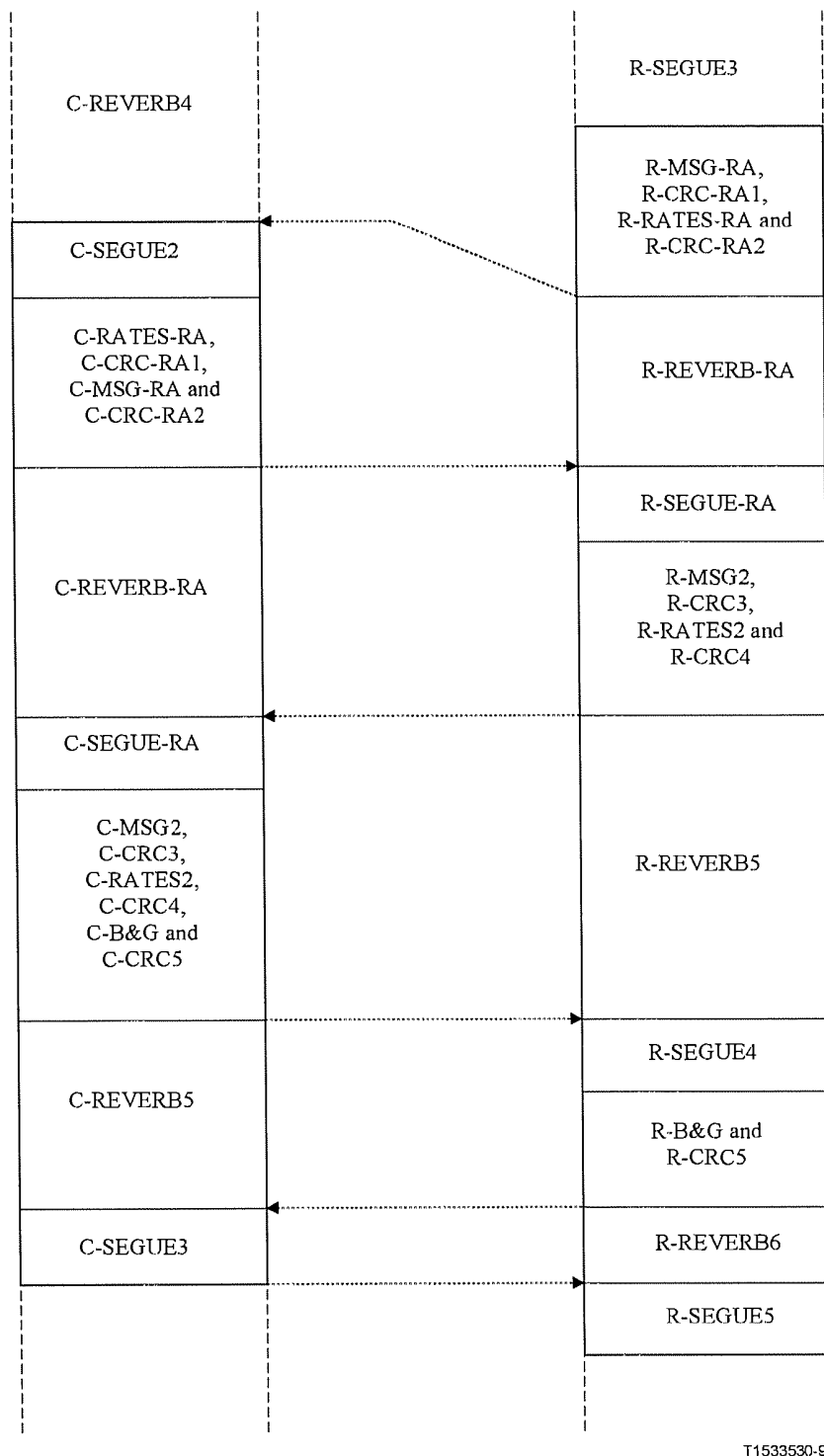
R-MEDLEY is a wideband pseudo-random signal used for estimation of the upstream SNR at the ATU-C. The data to be transmitted are derived from UPRD defined in 7.10.4. In contrast to R-REVERB1, however, the cyclic prefix is used and the data sequence continues from one symbol to the next (i.e.  $d_1$  to  $d_6$  are not re-initialized for each symbol). Because the sequence is of length 63, and 64 bits are used for each symbol, the subcarrier vector for R-MEDLEY changes from one symbol period to the next. R-MEDLEY is transmitted for 16 384 symbol periods. Following R-MEDLEY the ATU-R enters signalling state R-REVERB4.

#### **11.10.9 R-REVERB4**

R-REVERB4 is the same as R-REVERB3 (see 11.10.2). The duration of R-REVERB4 is 128 symbols. This signal marks the end of channel analysis, and R-SEGUE3 immediately follows R-REVERB4.

#### **11.11 Exchange – ATU-C**

The timing diagram of exchange is shown in Figure 26.



**Figure 26/G.992.2 – Timing diagram of exchange**

During exchange there are three events that shall cause the ATU-C to invoke the Initialization Reset Procedure: Timeouts, no acceptable options in a C-RATES2 message, and error detection by a crc checksum. The exchange procedure is partly synchronized between ATU-C and ATU-R, and partly interactive. During the interactive part (C-REVERB4, C-REVERB5, C-REVERB-RA) a timeout shall occur when the time in the C-REVERB4 state exceeds 6000 symbols or when the time in C-REVERB-RA or C-REVERB5 state exceeds 4000 symbols.

### 11.11.1 C-REVERB4

C-REVERB4 is similar to C-REVERB2 (see 11.7.8), the only difference being the addition of a cyclic prefix on every symbol, and a maximum duration of 6000 symbols. C-REVERB4 continues into the exchange procedure, and its duration is not fixed. The timeout features of C-REVERB4 are defined in this subclause.

If the ATU-C does not detect R-CRC-RA2 within 6000 symbols, it shall time out and reset to C-QUIET1. After detection of R-SEGUE3 through R-CRC-RA2, the ATU-C shall continue to transmit C-REVERB4 for another 80 symbols before progressing to state C-SEGUE2.

### 11.11.2 C-SEGUE2

The signal C-SEGUE2 is the same as C-SEGUE1 (see 11.9.1); the only difference is the addition of the cyclic prefix. The duration of C-SEGUE2 is ten symbol periods. Following C-SEGUE2 the ATU-C shall enter state C-RATES-RA to begin a second exchange of rates.

### 11.11.3 C-RATES-RA

C-RATES-RA is used to send four new options for transport configuration for both upstream and downstream. These options will, in general, be closer to the optimum bit rate for the channel than those in C-RATES1, and should be based on the channel information received in R-MSG-RA. A C-RATES-RA message content is not constrained by previous messages, e.g. C-RATES1 and R-MSG-RA.

The format of C-RATES-RA is the same as that of C-RATES1, except that the four-byte prefix ( $55\ 55\ 55\ 55_{16}$ ) is not transmitted, and the signal is transmitted eight bits per symbol, as defined for C-MSG2 (see 11.11.9). The duration of C-RATES-RA is 120 symbols.

The  $\{RS_F, R, S, I, FS(LS2)\}$  shall have the following syntax. It is a ten-byte quantity comprising (one byte each):

- The RRSI field contains Reed-Solomon FEC and interleaver parameters. The RRSI field contains a total of 80 bits organized as ten entries each of eight bits. The second entry in the RRSI field contains the parameter  $RS_I$ : The number of parity bytes per symbol in the downstream transmission direction with  $RS_I$  equal to R/S in bits 5 (MSB) to 0 (LSB). The third entry in the RRSI field contains the parameter S; S is the number of DFs per Reed-Solomon codeword in the downstream transmission direction in bits 5 (MSB) to 0 (LSB). The fourth entry contains the parameter I: The downstream interleave depth in codewords. The seventh entry in the RRSI field contains the parameter  $RS_I$ : The number of parity bytes per symbol in the upstream transmission direction with  $RS_I$  equal to R/S in bits 5 (MSB) to 0 (LSB). The eighth entry in the RRSI field contains the parameter S; S is the number of DFs per Reed-Solomon codeword in the upstream transmission direction in bits 5 (MSB) to 0 (LSB). The ninth entry contains the parameter I: The upstream interleave depth in codewords. All other bits in RRSI shall be set to  $0_b$ .

The four options are transmitted in order of decreasing preference. Table 33 summarizes C-RATES-RA and Table 34 summarizes the RRSI fields of C-RATES-RA.

**Table 33/G.992.2 – C-RATES-RA**

	Option 1			Option 2			Option 3			Option 4		
	$B_F$	$B_I$	RRSI	$B_F$	$B_I$	RRSI	$B_F$	$B_I$	RRSI	$B_F$	$B_I$	RRSI
Number of bytes	10	10	10	10	10	10	10	10	10	10	10	10



**Table 34/G.992.2 – RRSI fields of C-RATES-RA**

Entry #	Field		← bits →							
			7	6	5	4	3	2	1	0
1	RS <sub>F</sub>	Downstream	N/A to Recommendation G.992.2 – set to {00000000 <sub>b</sub> }							
2	R		0 <sub>b</sub>	0 <sub>b</sub>	value of R [MSB ↔ LSB]					
3	S		0 <sub>b</sub>	0 <sub>b</sub>	value of S [MSB ↔ LSB]					
4	I		I <sub>7</sub>	I <sub>6</sub>	I <sub>5</sub>	I <sub>4</sub>	I <sub>3</sub>	I <sub>2</sub>	I <sub>1</sub>	I <sub>0</sub>
5	FS(LS2)		N/A to Recommendation G.992.2 – set to {00000000 <sub>b</sub> }							
6	RS <sub>F</sub>	Upstream	N/A to Recommendation G.992.2 – set to {00000000 <sub>b</sub> }							
7	R		0 <sub>b</sub>	0 <sub>b</sub>	value of R [MSB ↔ LSB]					
8	S		0 <sub>b</sub>	0 <sub>b</sub>	value of S [MSB ↔ LSB]					
9	I		I <sub>7</sub>	I <sub>6</sub>	I <sub>5</sub>	I <sub>4</sub>	I <sub>3</sub>	I <sub>2</sub>	I <sub>1</sub>	I <sub>0</sub>
10	FS(LS2)		N/A to Recommendation G.992.2 – set to {00000000 <sub>b</sub> }							

**11.11.4 C-CRC-RA1**

C-CRC-RA1 is a cyclic redundancy check for detection of errors in the reception of C-RATES-RA1 at the ATU-R. Its relation to C-RATES-RA1 is the same as that of C-CRC3 to C-MSG2 (see 11.11.10). Its 16 bits shall be transmitted in two symbols (see 11.11.9). Following C-CRC-RA1, the ATU-C shall enter state C-MSG-RA.

**11.11.5 C-MSG-RA**

C-MSG-RA is the same in format as C-MSG1; the bit assignment is as shown in Table 35.

**Table 35/G.992.2 – Assignment of 48 bits of C-MSG-RA**

Suffix(es) of $m_i$ (Note 1)	Parameter (Note 2)
47-44	New ATU-R target noise margin
43-38	ATU-R minimum noise margin (–32 to + 31 dB)
37-32	ATU-R maximum noise margin (–32 to + 31 dB)
31-0	Reserved by ITU-T
NOTE 1 – Within the separate fields the least significant bits have the lowest subscripts.	
NOTE 2 – All reserved bits shall be set to 0 <sub>b</sub> .	
NOTE 3 – Minimum and maximum values are defined in Recommendation G.997.1.	
NOTE 4 – Only the minimum and maximum ATU-R noise margins are communicated to the ATU-R. This information is needed for the downstream B&G table calculation at the ATU-R. The minimum and maximum ATU-C noise margins are used locally at the ATU-C for the upstream B&G table calculation.	

The 48 bits are transmitted in six symbols (see 11.11.9) Following C-MSG-RA the ATU-C shall enter state C-CRC-RA2.

**11.11.6 C-CRC-RA2**

C-CRC-RA2 is a cyclic redundancy check for detection of errors in the reception of C-MSG-RA at the ATU-R. Its relation to C-MSG-RA is the same as that of C-CRC3 to C-MSG2 (see 11.11.10). Its 16 bits shall be transmitted in two symbols. Following C-CRC-RA2, the ATU-C shall enter state C-REVERB-RA.

**11.11.7 C-REVERB-RA**

C-REVERB-RA is the same as C-REVERB4. After detection of R-CRC4 the ATU-C shall continue to transmit C-REVERB-RA for at least another 80 symbols before moving to state C-SEGUE-RA.

**11.11.8 C-SEGUE-RA**

C-SEGUE-RA is the same as C-SEGUE2. Following C-SEGUE-RA the ATU-C shall enter state C-MSG2.

**11.11.9 C-MSG2**

C-MSG2 transmits a 32-bit message signal to the ATU-R. This message includes the total number of bits per symbol supported, the estimated upstream loop attenuation, and the performance margin with the selected rate option. The message,  $m$ , is defined by:

$$m = \{m_{31}, m_{30}, \dots, m_1, m_0\}$$

with  $m_0$  being transmitted first. The message components are defined in the following sub-clauses, and their assigned positions within the composite message,  $m$ , are defined in Table 36.

**Table 36/G.992.2 – Assignment of 32 bits of C-MSG2**

Suffix(es) of $m_i$ (Note 1)	Parameter (Note 2)
31-26	Estimated average loop attenuation
25-22	Reserved by ITU-T
21	Erase all stored profiles
20-16	Performance margin with selected rate option
15-9	Reserved by ITU-T
8-0	Total number of bits supported
NOTE 1 – Within the separate fields the least significant bits have the lowest subscripts.	
NOTE 2 – All reserved bits shall be set to 0 <sub>b</sub> .	

A total of four symbol periods are used to communicate the 32-bit message, with eight bits transmitted on each symbol. Two bits are encoded onto each of the subcarriers numbered 43 through 46 using the 4-QAM constellation labelling given in 7.10.3 (for the synchronization symbol) and 11.7.5 (for C-REVERB1). The same two bits are also encoded in the same way onto a set of backup carriers, namely, subcarriers 91 through 94. The least significant byte of the message is transmitted in the first symbol of C-MSG2, with the two least significant bits of each byte encoded onto carriers 43 and 91. In addition, the pilot, subcarrier 64, shall be modulated with (+,+). Following C-MSG2, the ATU-C shall enter signalling state C-CRC3.

**11.11.9.1 Estimated average upstream loop attenuation**

During channel analysis the ATU-C receiver estimates the upstream channel gain of each subcarrier in preparation for computing the SNR for each tone; it shall also calculate the average loop attenuation. This attenuation is defined as the difference between the maximum aggregate transmit

power of 12.5 dBm minus any power cutback currently in effect and the total received power, rounded to the nearest 0.5 dB.

The attenuation is encoded into bits 31-26 of C-MSG2 as the integer binary representation of twice the attenuation (e.g. if the average attenuation is 21.5 dB, then  $\{m_{31}, \dots, m_{26}\} = 101011_b$ ).

#### **11.11.9.2 Erase all stored profiles**

If the ATU-C sets this bit to 1<sub>b</sub>, then all profiles as defined in 12.1.1 at the ATU-R shall be erased.

#### **11.11.9.3 Performance margin with selected rate option**

The ATU-C receiver shall select one of the rate options sent from the ATU-C during C-RATES-RA with a satisfactory upstream performance margin. This selected option is encoded in C-RATES2. This margin (rounded to the nearest dB) is encoded into bits 20-16 of C-MSG2 using a conventional binary representation (e.g. if the margin is 9 dB then  $\{m_{20}, \dots, m_{16}\} = 01001_b$ ).

#### **11.11.9.4 Total number of bits per symbol supported**

The ATU-C receiver shall also calculate the maximum number of bits per symbol that the upstream channel can support with the performance margin defined in C-MSG-RA at an error rate of  $10^{-7}$ . This number is encoded into bits 8-0 using a conventional binary representation (e.g. if the maximum number of bits that can be supported is 127 (data rate = 508 kbit/s),  $\{m_8, \dots, m_0\} = 00111111_b$ ).

#### **11.11.10 C-CRC3**

C-CRC3 is a cyclic redundancy check for detection of errors in the reception of C-MSG2 at the ATU-R. The crc polynomial  $c(D)$  and generator polynomial  $g(D)$  are the same as for C-CRC1, as defined in 11.9.3. These 16 bits shall be transmitted in two symbol periods using the method described in 11.11.9. Following C-CRC3, the ATU-C shall enter state C-RATES2.

#### **11.11.11 C-RATES2**

C-RATES2 is the reply to R-RATES-RA. It combines the selected downstream option with the selected upstream option. It thus transmits the final decision on the rates that will be used in both directions.

The ATU-C shall not change the downstream option from that selected in R-RATES2.

The length of C-RATES2 is eight bits, and the bit pattern for C-RATES2 is shown in Table 37. Other bit patterns that are not specified in the table are reserved for future use. If none of the options requested during C-RATES1 or C-RATES-RA can be implemented, ATU-C then invokes the Initialization Reset Procedure for retraining. One symbol period is used to transmit these eight bits using the method described in 11.11.9. Following C-RATES2, the ATU-C shall enter signalling state C-CRC4.

**Table 37/G.992.2 – Bit pattern for C-RATES2**

<b>(Downstream, upstream)</b>	<b>Bit pattern for C-RATES2 (MSB first) (Note 1)</b>
(option 1, option 1)	00010001 <sub>b</sub>
(option 1, option 2)	00010010 <sub>b</sub>
(option 1, option 3)	00010100 <sub>b</sub>
(option 1, option 4)	00011000 <sub>b</sub>
(option 2, option 1)	00100001 <sub>b</sub>
(option 2, option 2)	00100010 <sub>b</sub>
(option 2, option 3)	00100100 <sub>b</sub>
(option 2, option 4)	00101000 <sub>b</sub>
(option 3, option 1)	01000001 <sub>b</sub>
(option 3, option 2)	01000010 <sub>b</sub>
(option 3, option 3)	01000100 <sub>b</sub>
(option 3, option 4)	01001000 <sub>b</sub>
(option 4, option 1)	10000001 <sub>b</sub>
(option 4, option 2)	10000010 <sub>b</sub>
(option 4, option 3)	10000100 <sub>b</sub>
(option 4, option 4)	10001000 <sub>b</sub>
all options fail	00000000 <sub>b</sub>
NOTE – All other bit patterns that are not shown are reserved for future use by ITU-T.	

If it is determined that none of the four options can be implemented with the connection the ATU-C shall invoke the Initialization Reset Procedure for retraining.

#### **11.11.12 C-CRC4**

C-CRC4 is a cyclic redundancy check for detection of errors in the reception of C-RATES2 at the ATU-R. Its relation to C-RATES2 is the same as that of C-CRC3 to C-MSG2. Its 16 bits shall be transmitted in two symbols (see 11.11.11). Following C-CRC4, the ATU-C shall enter state C-B&G.

#### **11.11.13 C-B&G**

C-B&G shall be used to transmit to the ATU-R the bits and gains information,  $\{b_1, g_1, b_2, g_2, \dots, b_{31}, g_{31}\}$ , that are to be used on the upstream carriers.  $b_i$  indicates the number of bits to be coded by the ATU-R transmitter onto the  $i$ th upstream carrier;  $g_i$  indicates the scale factor, relative to the gain that was used for that carrier during the transmission of R-MEDLEY, that shall be applied to the  $i$ th upstream carrier. Because no bits or energy will be transmitted at dc or one-half the sampling rate,  $b_0, g_0, b_{32}$  and  $g_{32}$  are all presumed to be zero and shall not be transmitted.

Each  $b_i$  shall be represented as an unsigned 4-bit integer, with valid  $b_i$ s lying in the range of zero to  $N_{upmax}$ , the maximum number of bits that the ATU-R is prepared to modulate onto any subcarrier, which is communicated in R-MSG1.

Each  $g_i$  shall be represented as an unsigned 12-bit fixed-point quantity, with the binary point assumed just to the right of the third most significant bit. For example, a  $g_i$  with binary representation (most significant bit listed first) 001<sub>b</sub>.010000000<sub>b</sub> would instruct the ATU-R to scale

the constellation for carrier  $i$ , by a gain factor of 1.25, so that the power in that carrier shall be 1.94 dB higher than it was during R-MEDLEY.

For subcarriers on which no data are to be transmitted, and the receiver will never allocate bits (e.g. out-of-band subcarriers) both  $b_i$  and  $g_i$  shall be set to zero (0000<sub>b</sub> and 00000000.0000<sub>b</sub>, respectively) For subcarriers on which no data are to be currently transmitted, but the receiver may allocate bits later (e.g. as a result of an SNR improvement), the  $b_i$  shall be set to zero and the  $g_i$  to a value in the 0.19 to 1.33 range (000.001100000<sub>b</sub> to 001.010101011<sub>b</sub>).

The C-B&G information shall be mapped in a 496-bit (62 byte) message  $m$  defined by:

$$m = \{m_{495}, m_{494}, \dots, m_1, m_0\} = \{g_{31}, b_{31}, \dots, g_1, b_1\},$$

with the MSB of  $b_i$  and  $g_i$  in the higher  $m$  index and  $m_0$  being transmitted first. The message  $m$  shall be transmitted in 62 symbols, using the transmission method as described in 11.11.9.

Following C-B&G, the ATU-C shall enter the state C-CRC5.

#### 11.11.14 C-CRC5

C-CRC5 is a cyclic redundancy check for detection of errors in the reception of C-B&G at the ATU-R. Its relation to C-B&G is the same as that of C-CRC3 to C-MSG2. Its 16 bits shall be transmitted in two symbols (see 11.11.9). Following C-CRC5, the ATU-C shall enter state C-REVERB5.

#### 11.11.15 C-REVERB5

C-REVERB5 is the same as C-REVERB4 (see 11.11.1). The only difference is the maximum duration of 4000 symbols. The duration of C-REVERB5 depends upon the state of the ATU-R and the internal processing of the ATU-C. The ATU-C shall transmit C-REVERB5 until it has received, checked the reliability of, and established in the ATU-C transmitter, the downstream bits and gains information contained in R-B&G. If bits and gains information is not received, checked and established within 4000 symbols, the ATU-C shall timeout and invoke the Initialization Reset Procedure. The ATU-C shall enter state C-SEGUE3 as soon as it is prepared to transmit according to the conditions specified in R-B&G.

#### 11.11.16 C-SEGUE3

C-SEGUE3 is used to notify the ATU-R that the ATU-C is about to enter the steady-state signalling state C-SHOWTIME. The signal C-SEGUE3 is the same as C-SEGUE2 (see 11.11.2). The duration of C-SEGUE3 is ten symbol periods. Following C-SEGUE3 the ATU-C has completed initialization and shall enter state C-SHOWTIME.

### 11.12 Exchange – ATU-R

During exchange there are three cases when the ATU-R shall reset itself: Timeouts, no acceptable options in an R-RATES2 message, and error detection by a crc checksum. Both shall invoke the Initialization Reset Procedure. The exchange procedure is partly synchronized between ATU-C and ATU-R, and partly interactive. During the interactive parts (R-REVERB-RA, R-REVERB5 and R-REVERB6) a timeout shall occur when the time in either state exceeds 4000 symbols.

#### 11.12.1 R-SEGUE3

The signal R-SEGUE3 is the same as R-SEGUE2 (see 11.10.3). The duration of R-SEGUE3 is ten symbol periods. Following R-SEGUE3 the ATU-R shall enter state R-MSG-RA to begin a second exchange of rates.



**11.12.2 R-MSG-RA**

R-MSG-RA is similar to R-MSG2, but expanded by 48 bits. The bit assignments are as shown in Table 38.

**Table 38/G.992.2 – Assignment of 80 bits of R-MSG-RA**

Suffix(es) of $m_i$ (Note 1)	Parameter (Note 2)
79-56	Reserved by ITU-T
55-49	Number of RS overhead bytes, (R)
48-40	Number of RS payload bytes, K
39-32	Number of tones carrying data (ncloaded)
31-25	Estimated average loop attenuation
24-21	Coding gain
20-16	Performance margin with selected rate option
15-14	Reserved by ITU-T
13-12	Reserved by ITU-T
11-0	Total number of bits per DMT symbol, $B_{\max}$ .
NOTE 1 – Within the separate fields the least significant bits have the lowest subscripts.	
NOTE 2 – All reserved bits shall be set to 0 <sub>b</sub> .	

**11.12.2.1 Number of RS overhead bytes (R)**

This is the  $R$  (as defined in 7.5) parameter used to calculate  $B_{\max}$ . This parameter shall be calculated with  $S = 1$ .

**11.12.2.2 Number of RS payload bytes (K)**

This is the  $K$  (as defined in 7.3.3) parameter used to calculate  $B_{\max}$ . This parameter shall be calculated with  $S = 1$ .

**11.12.2.3 Number of tones carrying data (ncloaded)**

This is the number of subcarriers with  $b_i > 0$  used to calculate  $B_{\max}$ .

**11.12.2.4 Estimated average loop attenuation**

This parameter shall be defined as in R-MSG2; see 11.12.8.

**11.12.2.5 Coding gain**

The coding gain of RS FEC coding is used to calculate  $B_{\max}$ . The coding gain is expressed in steps of 0.5 dB in the 0 to 7.5 dB range.

**11.12.2.6 Performance margin with selected rate option**

This parameter shall be defined as in R-MSG2; see 11.12.8. If R-RATES-RA indicates "no option selected", then this parameter shall be set to 0 or reflect the performance margin in dB corresponding to  $B_{\max}$  (which may be 0 to 3 dB above the minimum requested SNR margin). This field is encoded as in 11.12.8.3.

**11.12.2.7 Total number of bits supported ( $B_{\max}$ )**

This parameter shall be defined as in R-MSG2; see 11.12.8.

**11.12.3 R-CRC-RA1**

R-CRC-RA1 is a cyclic redundancy check for detection of errors in the reception of R-MSG-RA. Its relation to R-MSG-RA is the same as that of R-CRC3 to R-MSG2. Following R-CRC-RA1, the ATU-R shall enter state R-RATES-RA.

**11.12.4 R-RATES-RA**

R-RATES-RA is the reply to C-RATES1 based on the results of the downstream channel analysis and is similar to R-RATES2. Instead of listing the data rates and formats as in C-RATES1, the ATU-R does one of the following:

- Sends back only the option number of the highest data rate that can be supported based on the measured SNR of the downstream channel (not taking into account impulse noise resilience).
- Indicates that no option selection was made at this time, but will be made later based on C-RATES-RA information.
- Indicates none of the options requested during C-RATES1 can be implemented.

As in R-RATES2, four bits are used for the option number. A total of eight bits are used for R-RATES-RA, and the bit patterns are shown in Table 39. Other bit patterns that are not specified in the table are reserved for future use. One symbol period is used to transmit these eight bits using the method described in 11.12.8. Following R-RATES-RA, the ATU-R shall enter state R-CRC-RA2.

The format of R-RATES-RA is the same as R-RATES2, except for the additional bit pattern used to indicate "no option selected".

**Table 39/G.992.2 – Bit pattern for R-RATES-RA**

<b>Downstream</b>	<b>Bit pattern for R-RATES2 (MSB first)</b>
option 1	00010001 <sub>b</sub>
option 2	00100010 <sub>b</sub>
option 3	01000100 <sub>b</sub>
option 4	10001000 <sub>b</sub>
no option selected	00000001 <sub>b</sub>
all options fail	00000000 <sub>b</sub>
NOTE – All other bit patterns that are not shown are reserved by ITU-T.	

**11.12.5 R-CRC-RA2**

R-CRC-RA2 is a cyclic redundancy check for detection of errors in the reception of R-RATES-RA. Its relation to R-RATES-RA is the same as that of R-CRC3 to R-MSG2. Following R-CRC-RA2, the ATU-R shall enter state R-REVERB-RA.

**11.12.6 R-REVERB-RA**

R-REVERB-RA is the same as R-REVERB3 (see 11.10.2) The duration of R-REVERB-RA depends upon the signalling state of the ATU-C and the internal processing of the ATU-R, but has a maximum of 4000 symbols. The ATU-R shall transmit R-REVERB-RA until it has received and checked the reliability of the upstream bits and gains information contained in C-RATES-RA. After the ATU-R has received C-CRC-RA2, it shall continue to transmit R-REVERB-RA for another 64 symbols. It shall then enter R-SEGUE-RA.

If it has not successfully detected all the control signals within 4000 symbols it shall time out and invoke the Initialization Reset Procedure.

#### 11.12.7 R-SEGUE-RA

R-SEGUE-RA is the same as R-SEGUE4. Following R-SEGUE-RA the ATU-R shall enter state R-MSG2.

#### 11.12.8 R-MSG2

R-MSG2 transmits a 32-bit message signal to the ATU-C. This message includes the total number of bits per symbol supported, the estimated downstream loop attenuation, and the performance margin with the selected rate option. The message,  $m$ , is defined by:

$$m = \{m_{31}, m_{30}, \dots, m_1, m_0\}$$

with  $m_0$  being transmitted first. The message components are defined in the following subclauses, and their assigned positions within the composite message,  $m$ , are defined in Table 40.

**Table 40/G.992.2 – Assignment of 32 bits of R-MSG2**

Suffix(es) of $m_i$ (Note 1)	Parameter (Note 2)
31-25	Estimated average loop attenuation
24-22	Reserved by ITU-T
21	Erase all stored profiles
20-16	Performance margin with selected rate option
15-12	Reserved by ITU-T
11-0	Total number of bits supported
NOTE 1 – Within the separate fields the least significant bits have the lowest subscripts.	
NOTE 2 – All reserved bits shall be set to 0 <sub>b</sub> .	

A total of four symbol periods are used to communicate the 32-bit message, with eight bits transmitted on each symbol. Two bits are encoded onto each of the subcarriers numbered 10 through 13 using the 4-QAM constellation labelling given in 7.10.3 (for the synchronization symbol) and 11.7.5 (for C-REVERB1). The same two bits are also encoded in the same way onto a set of backup carriers, namely, subcarriers 20 through 23. The least significant byte of the message is transmitted in the first symbol of R-MSG2, with the two least significant bits of each byte encoded onto carriers 10 and 20. Following R-MSG2, the ATU-R shall enter state R-CRC3.

##### 11.12.8.1 Estimated average downstream loop attenuation

During channel analysis, the ATU-R receiver estimates the downstream channel gain of each subcarrier in preparation for computing the SNR for each tone; it shall also calculate the average loop attenuation. This attenuation is defined as the difference between ATU-C maximum aggregate transmit power of 17.2 dBm minus any power cutback currently in effect and the total received power, rounded to the nearest 0.5 dB.

The attenuation is encoded into bits 31-25 of R-MSG2 as the integer binary representation of twice the attenuation (e.g. if the average attenuation is 21.5 dB, then  $\{m_{31}, \dots, m_{25}\} = 0101011_b$ ).

##### 11.12.8.2 Erase all stored profiles

If the ATU-R sets this bit to 1<sub>b</sub>, then all profiles as defined in 12.1.1 at the ATU-C shall be erased.

**11.12.8.3 Performance margin with selected rate option**

The ATU-R receiver shall select one of the rates options sent from the ATU-C during C-RATES-RA with a satisfactory downstream margin. This selected option is encoded in R-RATES2. This margin (rounded to the nearest dB) is encoded into bits 20-16 of R-MSG2 using a conventional binary representation (e.g. if the margin is 9 dB, then  $\{m_{20}, \dots, m_{16}\} = 01001_b$ ).

**11.12.8.4 Total number of bits per symbol supported**

The ATU-R receiver shall also calculate the maximum number of bits per symbol that the downstream channel can support with the performance margin defined in C-MSG-RA (at an error rate of  $10^{-7}$ ). This number is encoded into bits 11-0 using a conventional binary representation (e.g. if the maximum number of bits that can be supported is 1724 (data rate = 6896 kbit/s),  $\{m_{11}, \dots, m_0\} = 11010111100_b$ ).

**11.12.9 R-CRC3**

R-CRC3 is a cyclic redundancy check for detection of errors in the reception of R-MSG2 at the ATU-C. The crc polynomial  $c(D)$  and generator polynomial  $g(D)$  are as described in 11.9.3. These bits are transmitted in two symbol periods using the method described in 11.12.8. Following R-CRC3, the ATU-R shall enter state R-RATES2.

**11.12.10 R-RATES2**

R-RATES2 is the reply to C-RATES-RA based on the results of the downstream channel analysis. Instead of listing the data rates and formats as in C-RATES1, the ATU-R sends back only the option number of the selected data rate that can be supported based on the measured SNR of the downstream channel (not taking into account impulse noise resilience). As in C-RATES2, four bits are used for the option number. A total of eight bits are used for R-RATES2, and the bit patterns are shown in Table 41. If none of the options requested during C-RATES1 can be implemented, the ATU-R shall invoke the Initialization Reset Procedure. One symbol period is used to transmit these eight bits using the method described in 11.12.8. Following R-RATES2, the ATU-R shall enter state R-CRC4.

**Table 41/G.992.2 – Bit pattern for R-RATES2**

Downstream	Bit pattern for R-RATES2 (MSB first)
option 1	00010001 <sub>b</sub>
option 2	00100010 <sub>b</sub>
option 3	01000100 <sub>b</sub>
option 4	10001000 <sub>b</sub>
all options fail	00000000 <sub>b</sub>
NOTE – All other bit patterns that are not shown are reserved by ITU-T.	

If it is determined that none of the four options can be implemented with the connection, the ATU-R shall invoke the Initialization Reset Procedure for retraining.

**11.12.11 R-CRC4**

R-CRC4 is a cyclic redundancy check for detection of errors in the reception of R-RATES2 at the ATU-C. Its relation to R-RATES2 is the same as that of R-CRC3 to R-MSG2. Following R-CRC4, the ATU-R shall enter state R-REVERB5.

**11.12.12 R-REVERB5**

R-REVERB5 is the same as R-REVERB3 (see 11.10.2). The duration of R-REVERB5 depends upon the signalling state of the ATU-C and the internal processing of the ATU-R, but has a maximum of 4000 symbols. The ATU-R shall transmit R-REVERB5 until it has received and checked the reliability of the upstream bits and gains information contained in C-B&G. After the ATU-R has received C-CRC5, it shall continue to transmit R-REVERB5 for another 64 symbols. It shall then enter R-SEGUE4. If it has not successfully detected all the control signals within 4000 symbols, it shall timeout and invoke the Initialization Reset Procedure.

**11.12.13 R-SEGUE4**

The purpose of R-SEGUE4 is to notify the ATU-C that the ATU-R is about to enter R-B&G. R-SEGUE4 is the same as R-SEGUE3 (see 11.12.1). The duration of R-SEGUE4 is ten symbol periods. Following R-SEGUE4 the ATU-R shall enter state R-B&G.

**11.12.14 R-B&G**

The purpose of R-B&G is to transmit to the ATU-C the bits and gains information,  $\{b_1, g_1, b_2, g_2, \dots, b_{127}, g_{127}\}$ , to be used on the downstream subcarriers.  $b_i$  indicates the number of bits to be coded by the ATU-C transmitter onto the  $i$ th downstream subcarrier;  $g_i$  indicates the scale factor that shall be applied to the  $i$ th downstream subcarrier, relative to the gain that was used for that carrier during the transmission of C-MEDLEY. Because no bits or energy will be transmitted at DC or one-half the sampling rate,  $b_0, g_0, b_{128}$ , and  $g_{128}$  are all presumed to be zero, and are not transmitted. Because subcarrier 64 is reserved as the pilot tone,  $b_{64}$  shall be set to 0 and  $g_{64}$  shall be set to  $g_{\text{sync}}$ . The value  $g_{\text{sync}}$  represents the gain scaling applied to the sync symbol and is defined in Annexes A, B and C.

Each  $b_i$  is represented as an unsigned four-bit integer, with valid  $b_i$  lying in the range of zero to  $N_{\text{downmax}}$ , the maximum number of bits that the ATU-C is prepared to modulate onto any subcarrier, which is communicated in C-MSG1.

Each  $g_i$  is represented as an unsigned 12-bit fixed-point quantity, with the binary point assumed just to the right of the third most significant bit. For example, a  $g_i$  with binary representation (most significant bit listed first)  $001.01000000_2$  would instruct the ATU-C to scale the constellation for carrier  $i$  by a gain factor of 1.25, so that the power in that carrier shall be 1.94 dB higher than it was during C-MEDLEY.

For subcarriers on which no data are to be transmitted, and the receiver will never allocate bits (e.g. out-of-band subcarriers) both  $b_i$  and  $g_i$  shall be set to zero ( $0000_2$  and  $00000000.0000_2$ , respectively). For subcarriers on which no data are to be currently transmitted, but the receiver may allocate bits later (e.g. as a result of an SNR improvement), the  $b_i$  shall be set to zero and the  $g_i$  to a value in the 0.19 to 1.33 range ( $000.00110000_2$  to  $001.0101011_2$ ).

The R-B&G information shall be mapped in a 4080-bit (510 byte) message  $m$  defined by:

$$m = \{m_{4079}, m_{4078}, \dots, m_1, m_0\} = \{g_{255}, b_{255}, \dots, g_1, b_1\},$$

with the MSB of  $b_i$  and  $g_i$  in the higher  $m$  index and  $m_0$  being transmitted first. The message  $m$  shall be transmitted in 510 symbols, using the transmission method as described in 11.12.8.

The  $b_i$  and  $g_i$  values for  $i \geq 129$  and  $i \leq 255$  shall be set to 0.

Following R-B&G, the ATU-C shall enter the state R-CRC5.



#### **11.12.15 R-CRC5**

R-CRC5 is a cyclic redundancy check for detection of errors in the reception of R-B&G at the ATU-C. Its relation to R-B&G is the same as that of R-CRC3 to R-MSG2. Following R-CRC5, the ATU-R shall enter state R-REVERB6.

#### **11.12.16 R-REVERB6**

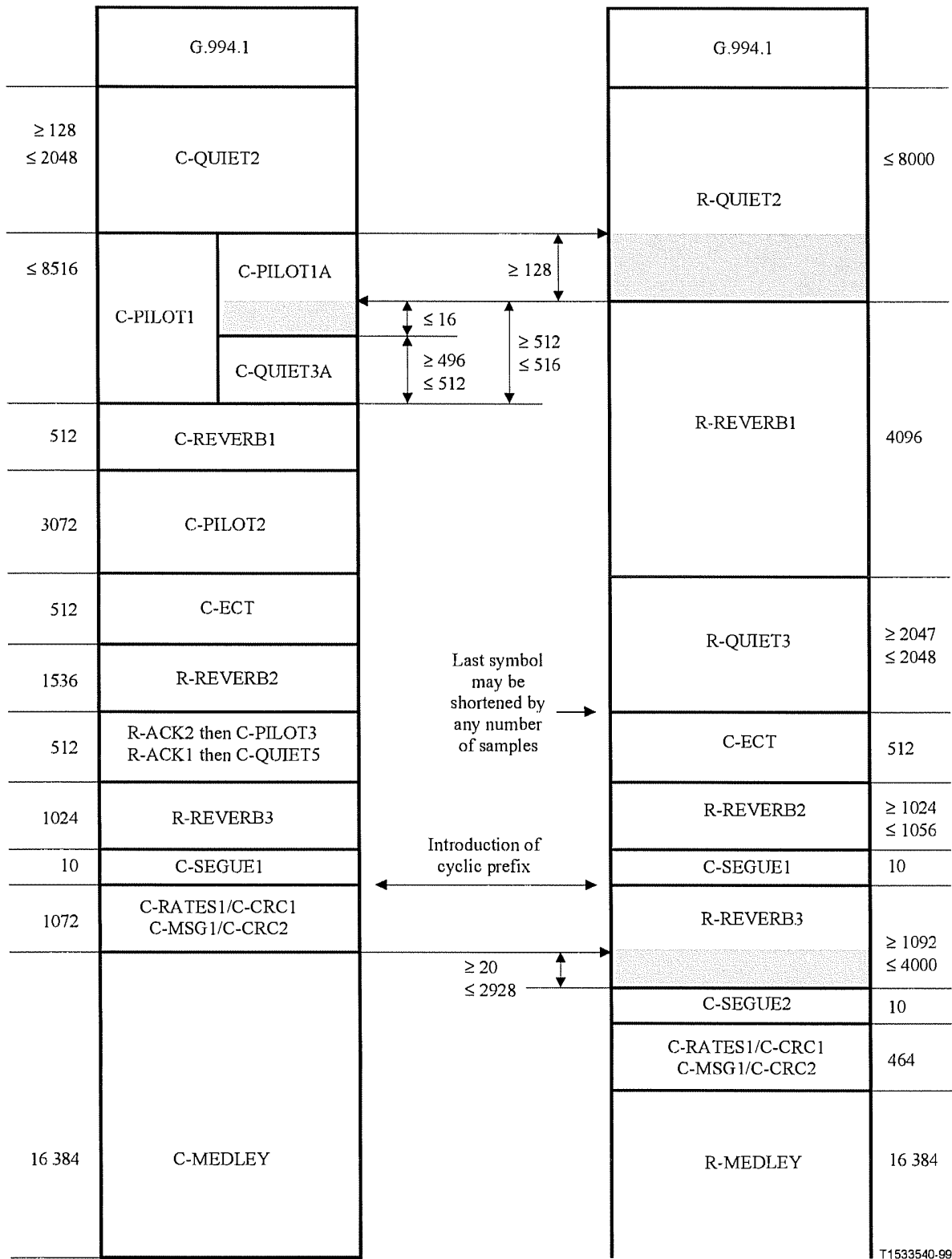
R-REVERB6 is the same as R-REVERB3 (see 11.10.2). The duration of R-REVERB6 depends upon the signalling state of the ATU-C and the internal processing of the ATU-R, but has a maximum of 4000 symbols. The ATU-R shall transmit R-REVERB6 until it has detected all ten symbols of C-SEGUE3; it shall then enter R-SEGUE5. If it has not successfully detected C-SEGUE3 within 4000 symbols, it shall time out and invoke the Initialization Reset Procedure.

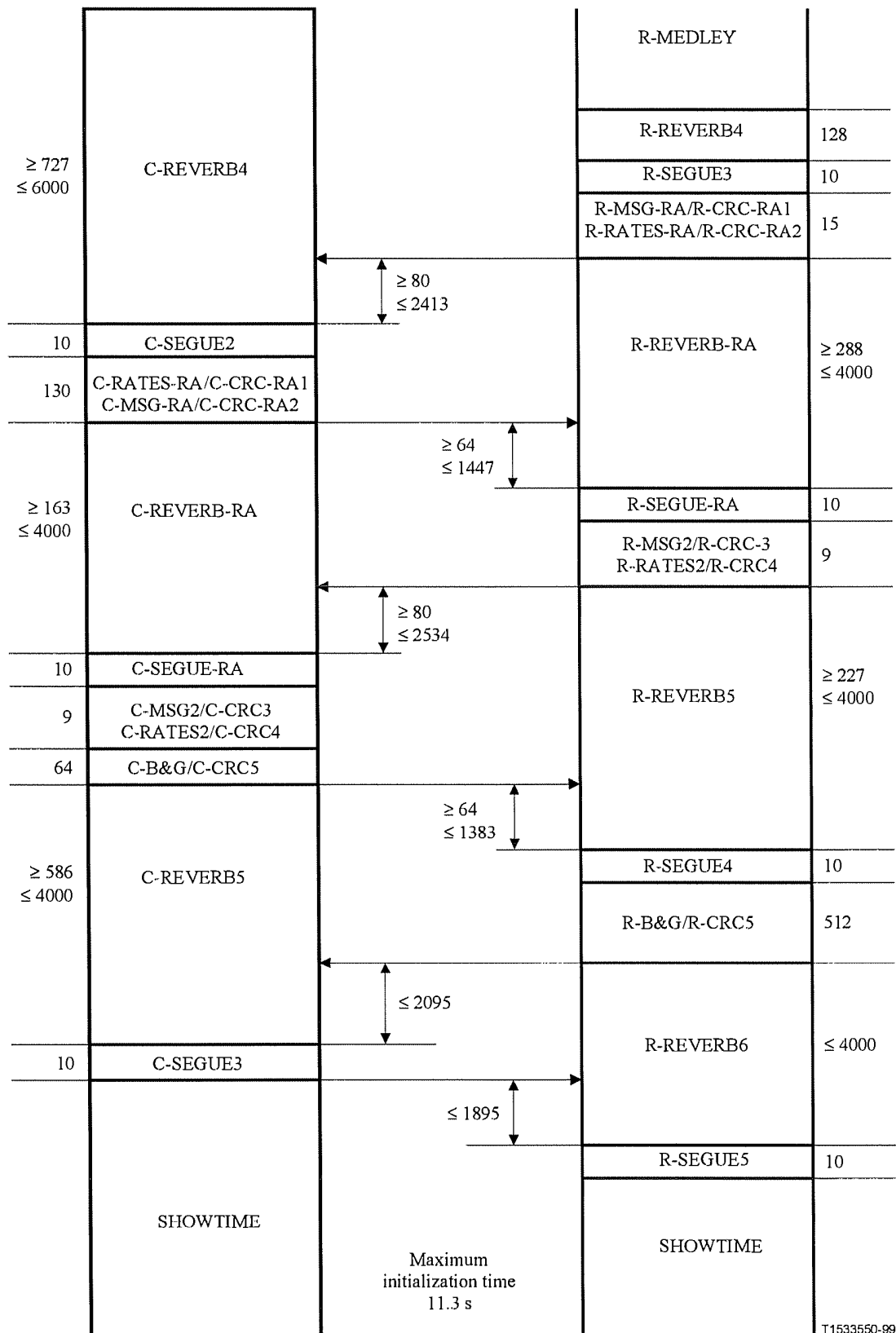
#### **11.12.17 R-SEGUE5**

The purpose of R-SEGUE5 is to notify the ATU-C that the ATU-R is about to enter the steady-state signalling state R-SHOWTIME. R-SEGUE5 is identical to R-SEGUE3 (see 11.12.1). The duration of R-SEGUE5 is ten symbol periods. Following R-SEGUE5 the ATU-R has completed initialization and shall enter state R-SHOWTIME.

### **11.13 Details of initialization timing**

The requirements for the initialization sequence (as defined in 11.1 through 11.12) are shown in Figures 27 and 28. Figure 27 shows the first part of the initialization sequence, up to C-MEDLEY and R-MEDLEY. Figure 28 shows the rest of the initialization sequence.

Figure 27/G.992.2 – Timing diagram of initialization sequence (*part 1*)

Figure 28/G.992.2 – Timing diagram of initialization sequence (*part 2*)

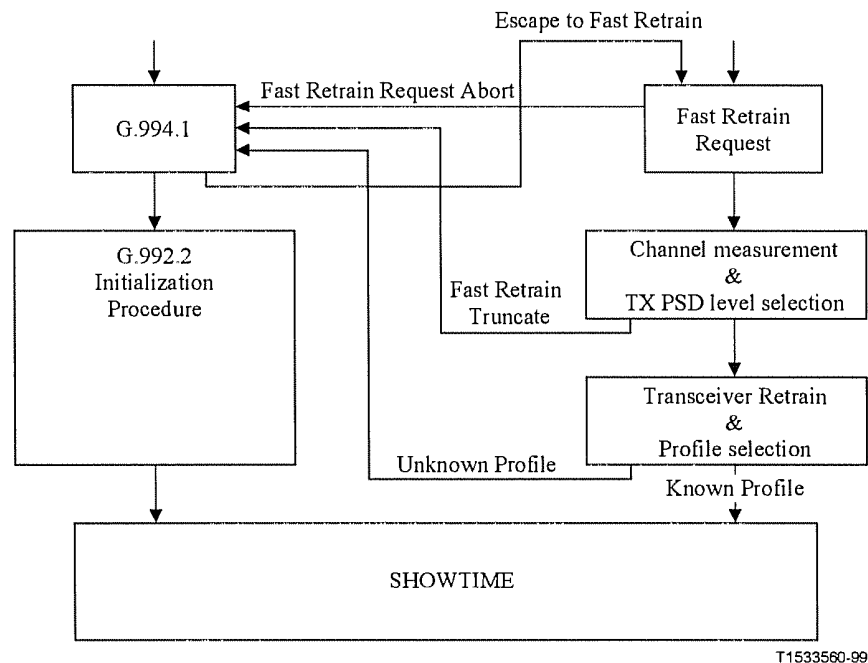
## 12 Fast Retrain

## 12.1 Fast Retrain overview

A Fast Retrain Procedure is defined to adapt transmission characteristics to changing line conditions caused by e.g. phone on/off hook transitions. The Fast Retrain Procedure is also used in an Escape from Handshake to Fast Retrain and in Power Management transitions.

Figure 29 shows the flowchart of the various components of the Fast Retrain Procedure and how it relates to the Initialization procedures in clause 11.

If errors occur during SHOWTIME, a Fast Retrain Procedure may also be invoked.



**Figure 29/G.992.2 – Flowchart of Fast Retrain**

### 12.1.1 Profile requirements

The Fast Retrain Procedure is based on the concept of stored profiles.

The ATU shall support a minimum of two profiles, being profiles zero and one. A maximum of 16 profiles may be supported, the highest profile number being 15.

The profiles shall at least contain the following information:

- B&G tables (as defined in 11.11.13 and 11.12.14);
- FEC parameters R and S (as defined in 7.5);
- Interleaver depth D (as defined in 7.6).

## 12.2 Definition of Fast Retrain signals

The following signals are used in the Fast Retrain Procedure and are defined as:

- R-RECOV is a single tone signal corresponding to subcarrier 20 without cyclic prefix.
- C-RECOV is a single tone signal corresponding to subcarrier 68 without cyclic prefix accompanied by the pilot subcarrier 64.

- C-REVERB-FR1 is similar to C-REVERB1.
- R-MSG-FR1 is a 16-bit message modulated using one bit per symbol modulation in the same manner as R-MSG1 in 11.10.6.
- The R-MSG-FR1 message,  $m$ , is defined by:

$$m = \{u_7, \dots, u_1, u_0, d_7, \dots, d_1, d_0\}$$

Bits  $d_4$  to  $d_0$  (LSB) indicate the Relative Downstream Fast Retrain Power Cutback PSD level and represent the power cutback in 2-dB steps (maximum of 62 dB power cutback). Bit  $d_5$  is the "Fast Retrain Truncate" bit (see 12.7) and is used to indicate that the ATU-R requests to truncate the fast retrain sequence and exit to the full initialization sequence. Bits  $d_7$  and  $d_6$  are reserved and set to 0<sub>b</sub>. The least significant bit  $d_0$  is transmitted first. Table 42 defines the relationship between the PSD level and the values for  $\{d_4, d_3, d_2, d_1, d_0\}$ .

**Table 42/G.992.2 – Relative Downstream Fast Retrain Power Cutback**

Decimal value of $\{d_4, d_3, d_2, d_1, d_0\}$	Relative Downstream Fast Retrain Power Cutback (dB)
0	0
1	2
...	...
31	62

Bits  $u_4$  to  $u_0$  (LSB) indicate the Absolute Upstream Fast Retrain Power Cutback PSD level and represent the power cutback in 2-dB steps (maximum of 62 dB power cutback). Bits  $u_7$  to  $u_5$  are reserved and set to 0<sub>b</sub>. The least significant bit,  $u_0$ , is transmitted first. Table 43 defines the relationship between the PSD levels and the values for  $\{u_4, u_3, u_2, u_1, u_0\}$ .

**Table 43/G.992.2 – Absolute Upstream Fast Retrain Power Cutback**

Decimal value of $\{u_4, u_3, u_2, u_1, u_0\}$	Absolute Upstream Fast Retrain Power Cutback (dB)
0	0
1	2
...	...
31	62

- R-CRC-FR1 relates to R-MSG-FR1 as R-CRC2 relates to R-MSG1.
- C-MSG-FR1 is a 16-bit message modulated using one bit per symbol modulation, in the same manner as C-MSG1 in 11.9.4.

The message,  $m$ , is defined by:

$$m = \{b_{15}, \dots, b_1, b_0\}$$

Bits  $b_4$  to  $b_0$  indicate the Fast Retrain Politeness Power Cutback (maximum of 62 dB power cutback) with respect to the Nominal downstream PSD Level as used by the preceding C-REVERB-FR1 signal. Bit  $b_5$  is the "Fast Retrain Truncate" bit and is used to indicate that the ATU-C requests to truncate the Fast Retrain Procedure and exit to the Initialization procedure. The other bits are reserved and set to 0<sub>b</sub>. The least significant bit,  $b_0$ , is



transmitted first. Table 44 defines the relationship between the Fast Retrain Politeness Power Cutback levels and the values for  $\{b_4, b_3, b_2, b_1, b_0\}$ .

**Table 44/G.992.2 – Fast Retrain Politeness Power Cutback**

Decimal value of $\{b_4, b_3, b_2, b_1, b_0\}$	Fast Retrain Politeness Power Cutback (dB)
0	0
1	2
...	...
31	62

- C-CRC-FR1 relates to C-MSG-FR1 as C-CRC2 relates to C-MSG1 in 11.10.6.
- R-MSG-FR2 is a 16-bit message indicating the downstream line profile selected by the ATU-R. The modulation method is identical to R-MSG-FR1.

The message,  $m$ , is defined by:

$$m = \{m_{15}, m_{14}, \dots, m_1, m_0\}$$

Bits  $m_3$  to  $m_0$  represent the line profile index (up to 16 profiles, with profile index LSB in  $m_0$ ). Bit  $m_4$  is used to indicate a "Known Profile" ( $0_b$ ) or an "Unknown Profile" ( $1_b$ ). The other bits are reserved and set to  $0_b$ . The least significant bit,  $m_0$ , is transmitted first.

- R-CRC-FR2 relates to R-MSG-FR2 as R-CRC2 relates to R-MSG1.
- C-MSG-FR2 is a 16-bit message indicating the upstream line profile selected by the ATU-C. The modulation method is identical to C-MSG-FR1.

The message,  $m$ , is defined by:

$$m = \{m_{15}, m_{14}, \dots, m_1, m_0\}$$

with  $m_0$  being the least significant bit, being transmitted first. Bits  $m_3$  to  $m_0$  represent the line profile index (up to 16 profiles, with profile index LSB in  $m_0$ ). Bit  $m_4$  is used to indicate an "Known Profile" ( $0_b$ ) or an "Unknown Profile" ( $1_b$ ). The other bits are reserved and set to  $0_b$ . The least significant bit,  $m_0$ , is transmitted first.

- C-CRC-FR2 relates to C-MSG-FR2 as C-CRC2 relates to C-MSG1.

## 12.2.1 Fast Retrain Signal power levels

### 12.2.1.1 ATU-C Fast Retrain Signal power levels

C-RECOV shall be transmitted at Nominal level.

C-REVERB-FR1 shall be transmitted at  $(-40 - \text{Fast Retrain Politeness Power Cutback})$  dBm/Hz level. The Fast Retrain Politeness Power Cutback level is obtained using Table 25. For this purpose, the average upstream loop attenuation may be estimated on measurement of R-REVERB1, R-RECOV and/or the ATU-R G.994.1 tones.

C-PILOT-FR1, C-REVERB-FR2, C-SEGUE-FR1, C-MSG-FR1 and C-CRC-FR1 are sent at the C-REVERB-FR1 PSD level.

All signals starting at C-REVERB-FR3 through C-SEGUE-FR4 are transmitted at  $(-40 - \text{Absolute Downstream Fast Retrain Power Cutback})$  dBm/Hz PSD level. However, because C-ECT-FR is a vendor-defined signal, the PSD specification shall only be interpreted as a maximum.

#### **12.2.1.2 ATU-R Fast Retrain Signal power levels**

R-RECOV shall be transmitted at Nominal level.

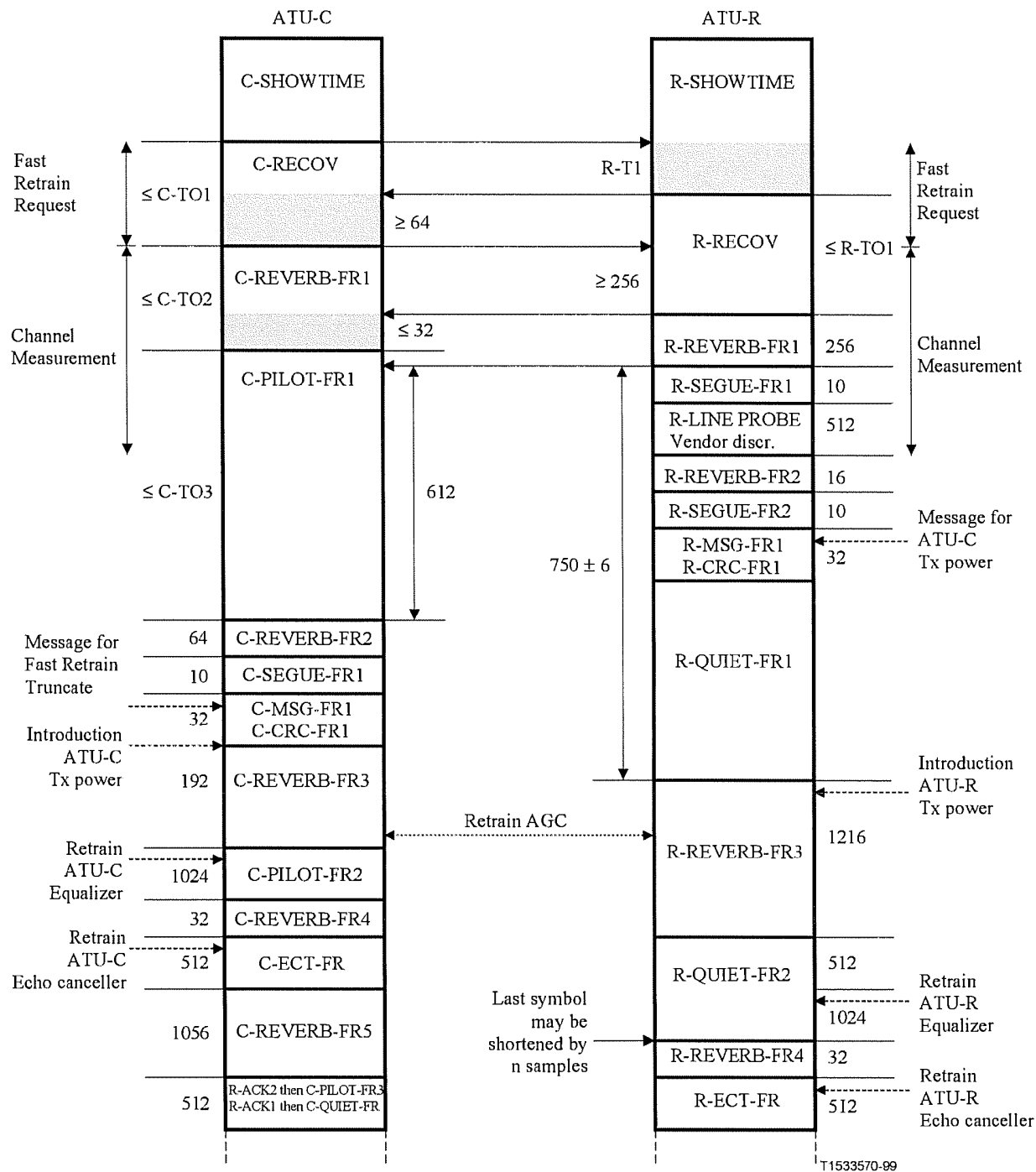
All signals starting at R-REVERB-FR1 through R-CRC-FR1 are transmitted at vendor-discretionary PSD levels less than or equal to  $-38$  dBm/Hz.

All signals starting at R-REVERB-FR3 through R-SEGUE-FR5 are transmitted at  $(-38 - \text{Absolute Upstream Fast Retrain Power Cutback})$  dBm/Hz PSD level. However, because R-ECT-FR is a vendor-defined signal, the PSD specification shall only be interpreted as a maximum.

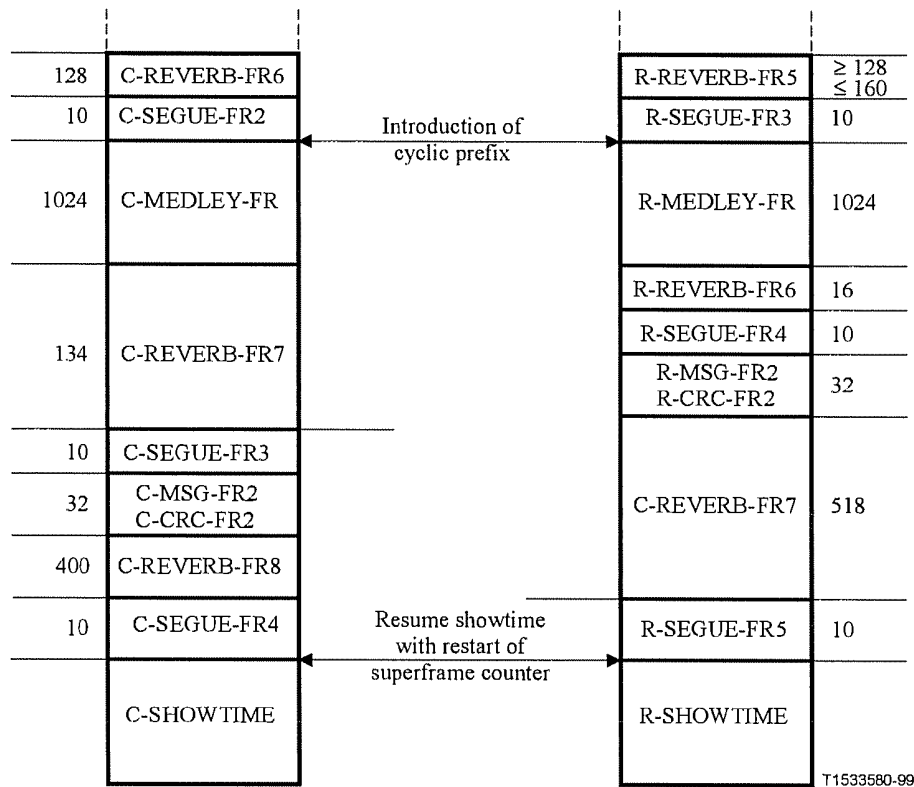
### **12.3 Fast Retrain Procedure**

#### **12.3.1 ATU-C initiated from SHOWTIME**

Figures 30 and 31 show the timing diagrams for the Fast Retrain with the ATU-C initiating the procedure. Time-outs C-TO1, C-TO2, C-TO3, R-TO1 are vendor discretionary. It is advisable to make these durations as short as possible, to keep the interruption of the physical layer to a minimum.



**Figure 30/G.992.2 – Timing Diagram of the Fast Retrain Procedure, ATU-C initiated from SHOWTIME (part 1)**



**Figure 31/G.992.2 – Timing Diagram of the Fast Retrain Procedure, ATU-C initiated from SHOWTIME (part 2)**

#### 12.3.1.1 ATU-C Fast Retrain Request

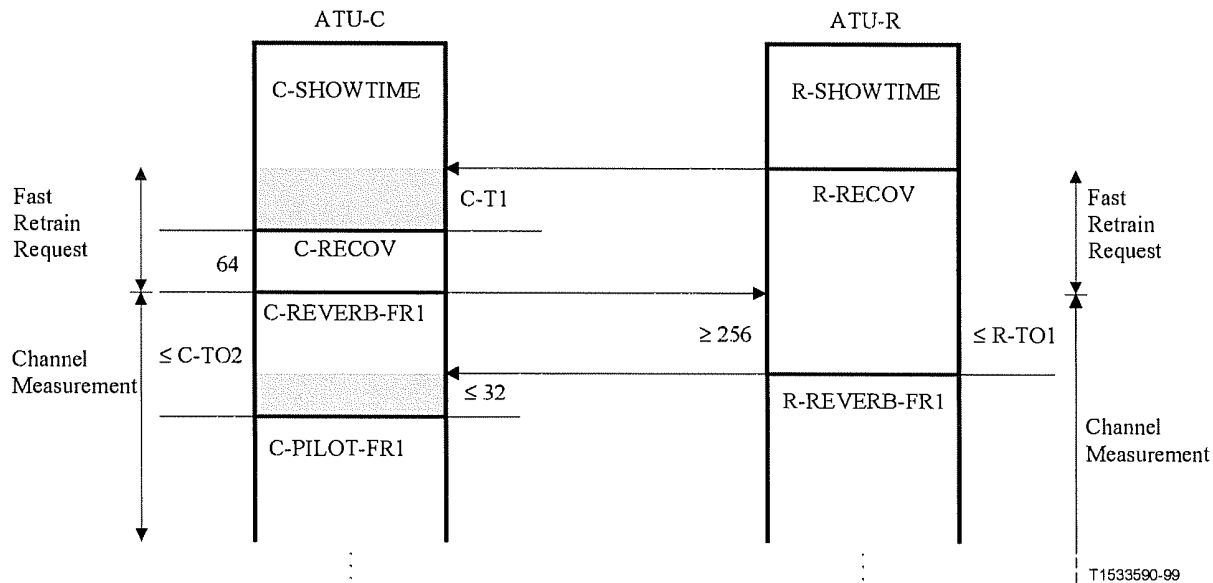
The ATU-R leaves R-SHOWTIME on request from the ATU-C within R-T1 symbols after reception of C-RECOV and begins transmission of R-RECOV.

After the reception of R-RECOV, the ATU-C shall send C-RECOV for a minimum period of 64 symbols, after which it starts to transmit C-REVERB-FR1 (with no cyclic prefix).

Time duration R-T1 is vendor discretionary. It is advisable to make these durations as short as possible because, during an on-off hook event, the R-SHOWTIME signal with a high power level is sent to the telephone set. This could lead to sound levels at the speaker which are unacceptable to the user, especially in the case of headset use.

### 12.3.2 ATU-R initiated from SHOWTIME

Figure 32 shows the timing diagram for the Fast Retrain mechanism as initiated by the ATU-R.



NOTE – Time-outs C-TO1, C-TO2, C-TO3, R-TO1 are vendor discretionary. It is advisable to make these durations as short as possible, to keep the interruption of the physical layer to a minimum.

**Figure 32/G.992.2 – Timing diagram of the Fast Retrain Procedure, ATU-R initiated from SHOWTIME**

#### 12.3.2.1 ATU-R Fast Retrain Request

The Fast Retrain request is started by the ATU-R leaving R-SHOWTIME autonomously and beginning the transmission of R-RECOV.

After the reception of R-RECOV, the ATU-C leaves C-SHOWTIME and starts C-RECOV within C-T1 symbols after reception of R-RECOV. C-RECOV is transmitted for a period of 64 symbols after which it starts to transmit C-REVERB-FR1 (with no cyclic prefix).

The ATU-R shall detect a minimum of 256 symbols of C-REVERB-FR1 before switching from R-RECOV to R-REVERB-FR1. The ATU-C switches to C-PILOT-FR1 within 32 symbols after reception of the transition of R-RECOV to R-REVERB-FR1. The other parts of the Fast Retrain are identical to the ATU-C initiated case.

NOTE – Time duration C-T1 is vendor discretionary. It is advisable to make these durations as short as possible because, during an on-off hook event, the C-SHOWTIME, C-RECOV and C-REVERB-FR1 signals with high power levels are sent to the telephone set. This could lead to sound levels at the speaker which are unacceptable to the user, especially in the case of headset use.

#### 12.3.3 Channel measurement

The next part of the Fast Retrain procedure consists of a channel measurement.

The ATU-R shall detect a minimum of 256 symbols of C-REVERB-FR1 before switching from R-RECOV to R-REVERB-FR1. The ATU-C switches to C-PILOT-FR1 within 32 symbols after reception of the transition of R-RECOV to R-REVERB-FR1. The R-REVERB-FR1 signal (with no cyclic prefix) is sent for 256 symbols and followed by ten symbols of R-SEGUE-FR1.



The ATU-R follows the R-SEGUE-FR1 signal with 512 symbols of R-LINE PROBE. This signal allows the ATU-R to measure the echo/reflections to appropriately set the upstream Tx power.

#### 12.3.4 Selection of Tx power levels

The second part of the Fast Retrain procedure consists of the selection of the Tx power levels.

After R-LINE-PROBE, the ATU-R sends the R-MSG-FR1 message indicating the new Absolute Upstream Fast Retrain Power Cutback and Relative Downstream Fast Retrain Power Cutback PSD levels via the sequence of 16 symbols of R-REVERB-FR2, ten symbols of R-SEGUE-FR2, and R-MSG-FR1/R-CRC-FR1 (32 symbols). It is followed by R-QUIET-FR1, which is terminated  $750 \pm 6$  symbols after start of R-SEGUE-FR1, after which transmission R-REVERB-FR3 is begun.

At the ATU-C, the C-PILOT-FR1 signal is terminated 612 symbols after reception of R-SEGUE-FR1, after which the ATU-C sends a message indicating a Fast Retrain Truncate bit, via the sequence of 64 symbols of C-REVERB-FR2, ten symbols of C-SEGUE-FR1, and C-MSG-FR1/C-CRC-FR1 (32 symbols). Next, the transmission of C-REVERB-FR3 is begun.

#### 12.3.5 Transceiver retraining

The third part of the Fast Retrain procedure consists of retraining of the transceiver.

At the ATU-R, the R-REVERB-FR3 signal is sent for 1216 symbols, followed by 1536 symbols of R-QUIET-FR2 and 32 symbols of R-REVERB-FR4. The final symbol of R-QUIET-FR2 may be shortened by any number of samples (at a sampling rate of 276 kHz) in order to accommodate the transmitter to receiver frame alignment. R-REVERB-FR4 is immediately followed by 512 symbols of R-ECT-FR, a minimum of 128 and a maximum of 160 symbols of R-REVERB-FR5 and ten symbols of R-SEGUE-FR3.

At the ATU-C, the C-REVERB-FR3 signal is sent for 192 symbols, followed by 1024 of C-PILOT-FR2, 32 symbols of C-REVERB-FR4, 512 symbols of C-ECT-FR, 1056 symbols of C-REVERB-FR5, 512 symbols of C-PILOT-FR3 or C-QUIET-FR, depending on whether R-ACK2 or R-ACK1 was received during a preceding normal initialization procedure, 128 symbols of C-REVERB-FR6 and ten symbols of C-SEGUE-FR2.

The ATU-C after C-SEGUE-FR2 and the ATU-R after R-SEGUE-FR3, introduces the cyclic prefix and switches to transmitting the MEDLEY signal. The signals C-MEDLEY-FR and R-MEDLEY-FR are transmitted for 1024 symbols. This part of the Fast Retrain is intended for SNR measurement.

#### 12.3.6 Profile exchange

The last part of the Fast Retrain Procedure consists of profile exchange.

Following R-MEDLEY-FR, the ATU-R line profile selection is exchanged using 16 symbols of R-REVERB-FR6, followed by ten symbols of R-SEGUE-FR4 and the R-MSG-FR2/R-CRC-FR2 (32 symbols).

Following C-MEDLEY-FR, the ATU-C line profile selection is exchanged using 134 symbols of C-REVERB-FR7, followed by ten symbols of C-SEGUE-FR3 and the C-MSG-FR2/C-CRC-FR2 (32 symbols). Both the ATU-C and the ATU-R have independent profile selections, namely the ATU-C for upstream respectively the ATU-R for downstream.

The ATU-C sends the final sequence consisting of 400 symbols of C-REVERB-FR8, followed by 10 symbols of C-SEGUE-FR4, after which the C-SHOWTIME is resumed with restart of the superframe counter.

The ATU-R sends the final sequence consisting of 518 symbols of R-REVERB-FR7, which is followed by ten symbols of R-SEGUE-FR5. After this the R-SHOWTIME is resumed with restart of the superframe counter.

The PSD level used in SHOWTIME shall be the level communicated in R-MSG-FR1, even if the PSD level during which the profile was established is different.

#### 12.4 Fast Retrain Procedure – Unknown Profile Transition

If an "Unknown Profile" indicator is exchanged in R-MSG-FR2 and/or C-MSG-FR2, the Fast Retrain procedure is executed up to (and including) C-SEGUE-FR4/R-SEGUE-FR5.

Upon receiving an "Unknown Profile" bit the ATU-R shall invoke the Initialization Reset Procedure instead of resuming SHOWTIME. Upon receiving an "Unknown Profile" bit the ATU-C shall invoke the Initialization Reset Procedure.

#### 12.5 Fast Retrain Procedure – Initiated from L3 or Recommendation G.994.1

A Fast Retrain Procedure initiated from an idle link state or via an Escape from Handshake, shall be according to 13.4.5 or 11.5, except for a longer time duration for R-TO1 of the R-RECOV signal. This will allow for re-acquisition of loop timing at the ATU-R (see Figures 33 and 34).

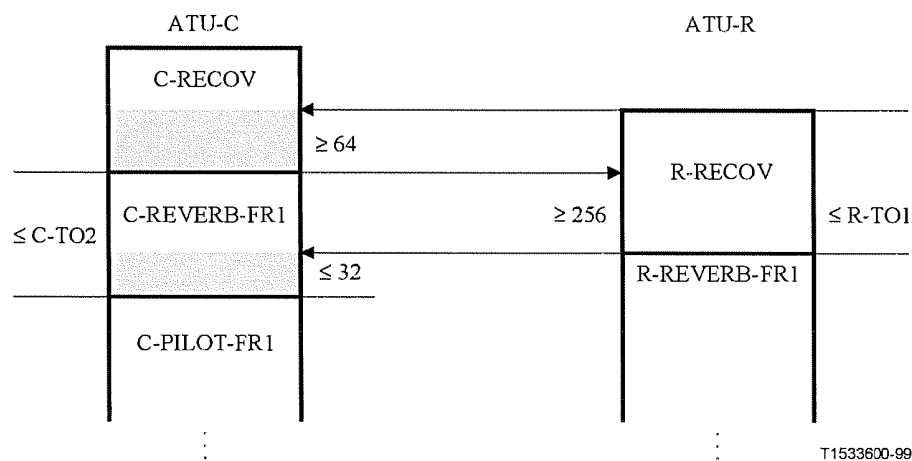


Figure 33/G.992.2 – Timing diagram of the Fast Retrain Procedure, ATU-C initiated from L3

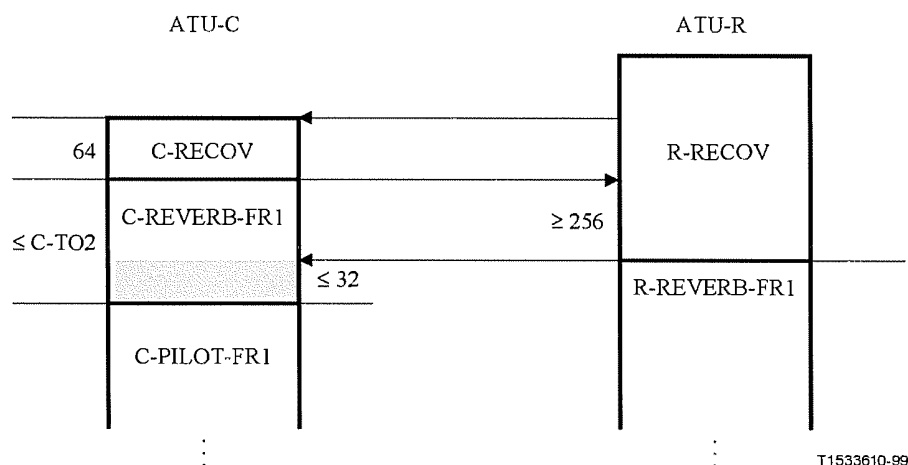


Figure 34/G.992.2 – Timing diagram of the Fast Retrain Procedure, ATU-R initiated from L3

## **12.6 Abort of Fast Retrain**

### **12.6.1 Abort of an ATU-C initiated Fast Retrain Request**

If, during the transmission of C-RECOV of an ATU-C initiated Fast Retrain Request, a R-TONES-REQ signal is detected by the ATU-C, the ATU-C shall abort the C-RECOV signal and respond with an Initialization Reset Procedure starting with C-TONES (i.e. HSTU-R initiated duplex startup procedure as defined in Recommendation G.994.1).

### **12.6.2 Abort of an ATU-R initiated Fast Retrain Request**

If, during the transmission of R-RECOV of an ATU-R initiated Fast Retrain Request, a C-TONES signal is detected by the ATU-R, the ATU-R shall abort the R-RECOV signal and respond with an Initialization Reset Procedure starting with R-TONES-REQ (i.e. HSTU-C initiated duplex startup procedure as defined in Recommendation G.994.1).

## **12.7 Fast Retrain Truncate**

If an ATU-R has no valid profiles, it may truncate the Fast Retrain Procedure prematurely after R-CRC-FR1, by setting the Fast Retrain Truncate bit in R-MSG-FR1.

If an ATU-C has no valid profiles, it may truncate the Fast Retrain Procedure prematurely after C-CRC-FR1, by setting the Fast Retrain Truncate bit in C-MSG-FR1.

If the Fast Retrain Truncate bit is set to 1<sub>b</sub> in R-MSG-FR1 or C-MSG-FR1, the Fast Retrain Procedure is executed up to (and including) C-CRC-FR1 and R-QUIET-FR1.

Instead of continuing with the Fast Retrain Procedure, the ATU-R or ATU-C shall invoke the Initialization Reset Procedure.

## **12.8 Fast Retrain Reset Procedure**

If errors or malfunctions are detected or time-out limits are exceeded at various points in the Fast Retrain sequence, either an Initialization Reset Procedure or a Fast Retrain Reset Procedure shall be executed. An ATU executes a Fast Retrain Reset Procedure by transitioning to the Fast Retrain Request. An ATU-R invoking the Fast Retrain Reset Procedure shall transition to R-RECOV. An ATU-C invoking the Fast Retrain Reset Procedure shall transition to C-RECOV.

## **13 Power management**

### **13.1 Introduction**

Power management defines a set of power management states for the ADSL link and the use of the eoc channel to coordinate power management between the ATUs. Power reduction can be achieved by minimizing the energy transmitted by the ATU onto the U-C and U-R reference points as well as by reducing the power consumed by the ATU (e.g. reducing clock speed, turning off drivers). This subclause defines a set of stable ADSL link states between the ATU-R and ATU-C by specifying the signals that are active on the link in each state. In addition, link transition events and procedures are defined in the subclause. The details of the ATU coordination with system power management functions are outside the scope of this Recommendation.

### 13.2 ADSL link states

ADSL link states are defined to allow an ATU to enter a low power state without totally disconnecting the link. These states are stable states and are generally not expected to be transitory. An ATU must support the ADSL link states shown as mandatory in Table 45.

**Table 45/G.992.2 – G.992.2 Power management states**

State	Name	Support	Description
L0	Full On	Mandatory	The ADSL link is fully functional.
L1	Low Power	Optional	The L1 state maintains full L0 state functionality at a lower net data rate (except for power management transitions). Power reduction in L1 can be achieved by methods provided in the exchange entry procedure (e.g. reduced data rate, reduced number of tones, and reduced power per tone). The reductions are implementation specific.
L2			Reserved for use by ITU-T.
L3	Idle	Mandatory	There is no signal transmitted at the U-C and U-R reference points. The ATU may be powered or unpowered in L3.

States L2 and L4 to L127 are reserved for use by ITU-T. States L128 to L255 are reserved for vendor-specific implementation.

### 13.3 Link state transitions

Link state transitions are initiated by various events. Events may arise from functions specified in this Recommendation (e.g. loss of power) or from functions outside the Recommendation's scope (e.g. changes in the line conditions that cause need for fast retrain or higher level requests to change power management states).

The following events are identified as potentially leading to link transitions:

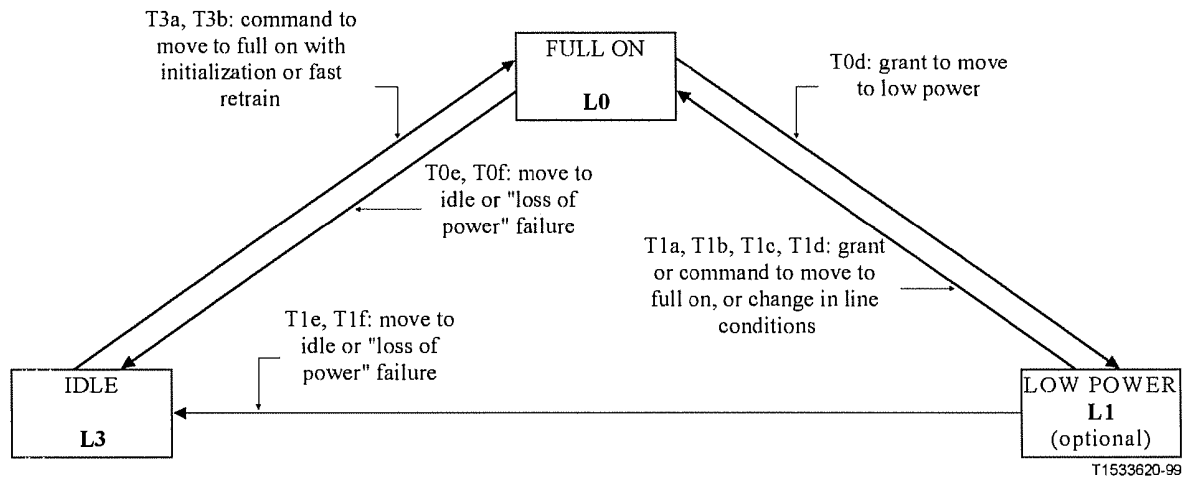
- Grant – This is a negotiated event and results from the successful eoc handshake result (see 13.5). The reason for initiating the eoc handshake (e.g. the request to enter into a lower power state) is outside the scope of the Recommendation. An unsuccessful eoc handshake does not result in a grant event.
- Command – This event results from an unconditional request to change states. The reason for requesting to change state (e.g. the request to move from idle to full on state) is outside the scope of the Recommendation.
- Change in line condition – This event results when the receiver detects that conditions have changed sufficiently to merit an initialization or fast retrain procedure. The method that the receiver uses to determine this (e.g. loss of suitable equalization, decrease of margin) is outside the scope of the Recommendation.
- Failure – This event is one of the defined failures in clause 10 (e.g. "loss of power" failure).

The allowed state transitions are listed in Table 46, and each is assigned a label string. The labelled power management transitions are shown in Figure 35.

**Table 46/G.992.2 – G.992.2 Power management transitions**

Label	Starting State	Resulting State	Event	Procedure
T0a	L0	L0	Change in line conditions require initialization at ATU-R or ATU-C.	Upon detection of initialization signals by ATU-R or ATU-C, the initialization procedure proceeds.
T0b	L0	L0	Change in line conditions require fast retrain at ATU-R or ATU-C.	Upon detection of fast retrain signals by ATU-R or ATU-C, the fast retrain procedure proceeds.
T0c	L0	L0	ATU-C or ATU-R is commanded to change link via the initialization procedure.	Same as procedure for T0a.
T0d	L0	L1	Grant event	Following successful eoc handshake initiated by the ATU-C or ATU-R, the exchange entry procedure is used.
T0e	L0	L3	Grant event	Following successful eoc handshake initiated by the ATU-C or ATU-R, the ATUs enter L3.
T0f	L0	L3	ATU-R detects "loss of power" failure.	Following detection of "loss of power" failure by the ATU-R, the ATU-R sends the corresponding indicator per clauses 8 and 10 and enter L3. The ATU-C enters L3 upon detection of the loss of power indication.
T1a	L1	L0	Change in line conditions require initialization at ATU-R or ATU-C.	Same as procedure for T0a.
T1b	L1	L0	Change in line conditions require fast retrain at ATU-R or ATU-C.	Same as procedure for T0b.
T1c	L1	L0	ATU-C or ATU-R is commanded to change link via the initialization procedure.	Same as procedure for T0a.
T1d	L1	L0	Grant event	Following successful eoc handshake initiated by the ATU-C or ATU-R, the fast retrain procedure is initiated by the ATU-R.
T1e	L1	L3	Grant event	Same as procedure for T0e.
T1f	L1	L3	ATU-R detects "loss of power" failure.	Same as procedure for T0f.
T3a	L3	L0	ATU-C or ATU-R is commanded to move to L0 via initialization.	Same as procedure for T0a.
T3b	L3	L0	ATU-C or ATU-R is commanded to move to L0 via fast retrain.	Upon detection of fast retrain signals by ATU-R or ATU-C, the fast retrain procedure proceeds as in 12.5.





**Figure 35/G.992.2 – Power management states**

The ATU-R and ATU-C coordinate transitions between power states using the procedures defined in 13.4 (e.g. eoc handshake, exchange entry procedure, fast retrain).

### 13.4 Link transition procedures

The transitions in this subclause shall be used when the corresponding power management events occur. Following completion of each of these procedures, the ATU-R shall update the Link State data register if the register does not conform to the current ADSL link state.

#### 13.4.1 Transitions from L0 to L0 (T0a, T0b, T0c)

The transitions T0a, T0b and T0c transitions are not strictly part of power management, but they have been included in this subclause for completeness and to discuss potential transitions to ADSL link state L3.

Transitions labelled T0a and T0c involve execution of the initialization procedure in clause 11. Successful execution of the initialization procedure will result in the ATU SHOWTIME state and power management state L0. However, if the initialization procedure cannot be successfully completed for some reason (e.g. there is no response to the initialization signals, repeated error conditions), a transition to power management state L3 may be initiated based upon vendor-discretionary methods.

The transition labelled T0b involves execution of the Fast Retrain Procedure. Successful execution results in the ATU SHOWTIME state and power management state L0. Additionally, the Fast Retrain Procedure may invoke the initialization procedure. If the initialization procedure cannot be completed for some reason, a transition to power management state L3 may be initiated based upon vendor-discretionary method.

#### 13.4.2 Transition from L0 to L1 (T0d)

The ATU-C or ATU-R may initiate the transition from L0 to L1 by using the eoc handshake (see 13.5).

Upon successful termination of the eoc handshake (indicated by the grant event), the Exchange entry procedure shall be used to adjust the parameters provided in the Exchange portion of the initialization procedure (e.g. data rate, number of tones, and power per tone).

**13.4.2.1 Exchange entry procedure**

This subclause defines the Exchange entry procedure. This procedure reuses states, signals, and rules for determining the next state contained within clause 11 as defined in the following steps:

- 1) After successful termination of the eoc handshake procedure, the ATU-R shall transmit R-QUIET-PM. R-QUIET-PM is defined as no transmitted signal onto the U-R interface. The ATU-R shall maintain loop timing and symbol timing during the R-QUIET-PM signal.
- 2) The ATU-C shall detect R-QUIET-PM, and respond by sending C-REVERB4 within N1 symbols on a symbol boundary. C-REVERB4 is defined in 11.11.1.
- 3) The ATU-R shall detect C-REVERB4 and respond by sending R-REVERB4 within TBD symbols (TBD to be sufficiently small so that loss of signal defect does not occur – Working value is 40). R-REVERB4 is defined in 11.10.9. The exchange portion of the initialization procedure defined in 11.11 and 11.12 shall continue from this point (i.e. the ATU-R shall send R-SEQUE3 after 128 symbols of R-REVERB4). During R-MSG-RA, the ATU-R shall use the "no options selected" message.

N1 is an implementation-specific number of symbols and shall be sufficiently small so that loss of signal defect does not occur at the ATU-C. Otherwise, the ATU-C implementation shall include a means that blocks the loss of signal defect during exchange entry procedure.

**13.4.3 Transitions from L1 to L0 (T1a, T1b, T1c, T1d)**

The ATU-C or ATU-R may initiate the transition labelled T1d from L1 to L0 by using the eoc handshake.

Upon successful termination of the eoc handshake (indicated by the grant event) the ATU-R shall begin the fast retrain procedure defined in clause 12 (i.e. start to transmit the R-RECOV signal).

In addition, either ATU may start the initialization procedure or Fast Retrain Procedure to move to L0 using transitions labelled T1a, T1b, and T1c. The reasons for generating the command events corresponding to these transitions are outside the scope of the Recommendation. Upon successful termination of the procedures, the ADSL link state is L0. However, if the initialization or Fast Retrain Procedures cannot be successfully completed for some reason (e.g. repeated error conditions), a transition to power management state L3 may be initiated based upon vendor discretionary methods.

**13.4.4 Transitions from L0 or L1 to L3 (T0e, T0f, T1e, T1f)****13.4.4.1 Orderly shutdown procedure**

The ATU-C or ATU-R may initiate the transitions to L3 labelled T0e and T1e by using the eoc handshake. These transitions should be used for orderly power-down procedure.

Upon successful termination of the eoc handshake (indicated by the grant event), the ATU-R shall stop transmitting. Upon detecting this, the ATU-C shall also stop transmitting.

**13.4.4.2 Disorderly shutdown procedure**

The ATU-R may initiate the transitions to L3 labelled T0f and T1f. These transitions should only be used if power is unexpectedly removed from the ATU-R.

Upon detection of the "loss of power" failure by the ATU-R, it shall send the dying gasp eoc command (see 8.3.3). Upon detection of the loss of signal indication, the ATU-C shall stop transmitting and enter L3.

**13.4.5 Transitions from L3 to L0 (T3a, T3b)**

Either ATU may start the initialization procedure to move to L0 using transitions labelled T3a. Alternately, the ATUs may initiate a fast retrain procedure as in the transition labelled T3b. The reasons for generating the command events corresponding to these transitions are outside the scope of the Recommendation.

For transition T3b, the ATUs shall use the fast retrain procedure with provision to recover timing when starting from the idle conditions, including the possibility to terminate the procedure as described in clause 12 for some reason (e.g. profiles were not maintained during off power condition in L3).

Upon successful termination of the procedures, the ADSL link state is L0. However, if the initialization or fast retrain procedures cannot be successfully completed for some reason (e.g. no response to training signals), the power management state is unchanged.

**13.5 eoc Handshake**

The eoc Handshake is used for power management coordination between the ATUs.

The eoc Handshake ends in either a successful or unsuccessful result. The successful result is defined as a grant event used to enable a power management state transition. The unsuccessful result does not trigger a state transition and the power management state is unchanged.

The handshake procedure includes a sequence of eoc commands defined in clause 8. If any of the eoc command, read, or write protocols used in the eoc handshake detects an eoc protocol error condition, the eoc handshake terminates in the unsuccessful result.

**13.5.1 ATU-R initiated eoc Handshake**

The ATU-R initiates the handshake using the following procedure.

- 1) The ATU-R shall write the value of the requested ADSL link state into the Link State data register.
- 2) The ATU-R sends a REQPDN eoc autonomous message.
- 3) After receiving a REQPDN message from the ATU-R, the ATU-C shall respond by reading the requested power down state from the Link State data register using the eoc read protocol.
- 4) After receiving the REQPDN message, the ATU-C may optionally propose an alternate ADSL link state by writing a different value into Link State data register using the eoc write protocol.
- 5) After determining that it can grant the state transition request, the ATU-C shall issue the GNTPDN eoc command using the eoc command protocol. If the eoc command protocol completes by receiving the echo of the command, the handshake ends with a successful result. If the eoc command protocol completes by receiving the UTC message, the handshake ends with an unsuccessful result.

If no response to the REQPDN eoc autonomous message is received from the ATU-C within 5 s, then the ATU-R shall resend the REQPDN message. If the ATU-R is in the middle of a multibyte read or write eoc protocol sequence, then the time-out count shall not begin until the end of the multi-byte sequence. Upon time-out, the ATU-R may send the REQPDN message up to four more times, after which the handshake procedure terminates with an unsuccessful result.

If the ATU-C is in the middle of a multi-byte read or write sequence when a REQPDN message is received, then the ATU-C may choose to terminate the multi-byte sequence or delay response until the end of the sequence.

If the ATU-C cannot grant the power down request for some reason (e.g. it does not support the requested state), it shall send the REJPDN eoc command using the eoc command protocol. After the ATU-R receives the REJPDN eoc command, the handshake ends with an unsuccessful result.

If the ATU-R cannot support the granted link state for some reason (e.g. the ATU-C responds via the optional write with a different ADSL link state, or the ATU-R no longer needs to go into the granted power down state), it shall respond to GNTPDN command with the UTC eoc message using the eoc command protocol.

### 13.5.2 ATU-C initiated eoc Handshake

The ATU-C initiates the eoc Handshake using the following procedure:

- 1) The ATU-C writes the value of the new ADSL link state into Link State data register using the eoc write protocol.
- 2) The ATU-C shall end the handshake sequence by issuing the GNTPDN eoc command using the eoc command protocol. If the eoc command protocol completes by receiving the echo of the command, the handshake ends with a successful result. If the eoc command protocol completes by receiving the UTC message, the handshake ends with an unsuccessful result.

If the ATU-R cannot support the granted link state for some reason (e.g. the ATU-R does not support the ADSL link state), then it shall respond to GNTPDN command with the UTC eoc message using the eoc command protocol.

## ANNEX A

### Non-overlapped spectrum operation

#### A.1 ATU-R transmitter PSD mask

Figure A.1 shows the Power Spectral Density (PSD) mask for an ATU-R transmitter operating in non-overlapped spectrum mode. The low frequency stop band is defined as the voice band. The high frequency stop band is defined as frequencies greater than 138 kHz. The slopes shown are approximate; refer to the equations for the exact slopes.

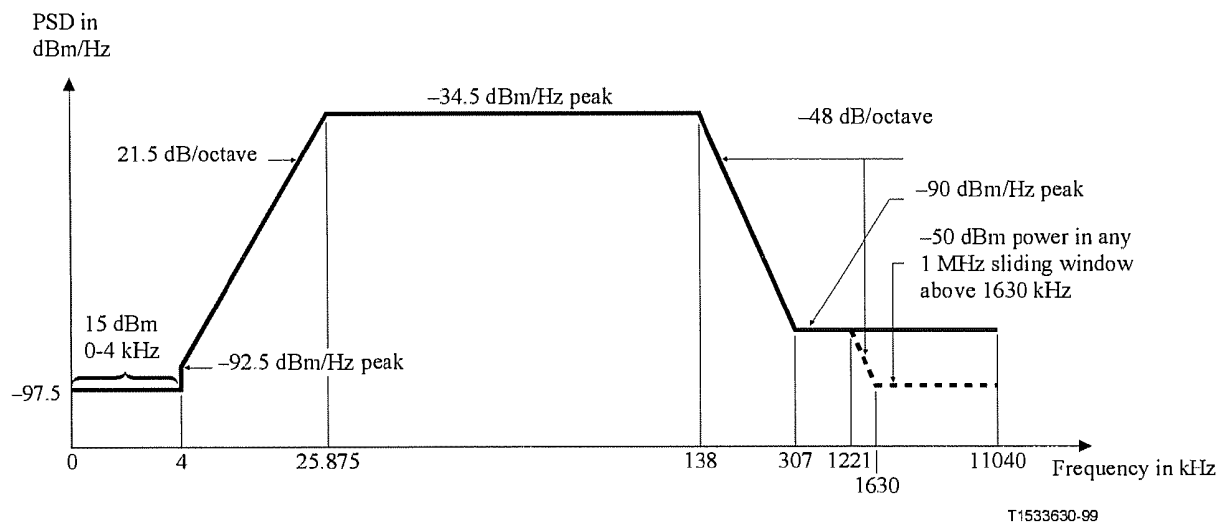


Figure A.1/G.992.2 – ATU-R transmitter PSD mask

Frequency band (kHz)	Equation for line (dBm/Hertz)	Impedance (Ohm)	Resolution bandwidth (kHz)
0-4	-97.5	100	4
	with +15 dBm power in 0-4 kHz window	600	
> 4-25.875	$-92.5 + 21.5 \times \log(f/4)/\log(2)$	100	
25.875-138	-34.5	100	10
138-307	$-34.5 - 48 \times \log(f/138)/\log(2)$	100	10
307-1221	-90	100	10
1221-1630	< -90 peak	100	10
	with max power in the $[f, f+1 \text{ MHz}]$ window of $(-90 - 48 \times \log(f/1221)/\log(2) + 60) \text{ dBm}$	100	1000
1630-11 040	< -90 peak	100	10
	with max power in the $[f, f+1 \text{ MHz}]$ window of -50 dBm	100	1000

#### A.1.1 Passband PSD ripple and group delay

The average PSD within the used passband shall be no greater than -38 dBm/Hz reduced by power cutback in steps of 2 dB. The lower end of the passband is implementation dependent. The upper end of the passband depends on whether the signal is for initialization (see A.1.2.1) or steady state (see A.1.2.3).

The passband ripple shall be no greater than +3.5 dB above the specified reference level; the maximum PSD  $(-38 - \text{Absolute Upstream Fast Retrain Power Cutback} + 3.5) \text{ dBm/Hz}$  applies across the whole band from 25.875 kHz to 138 kHz.

The group delay variation over the pass band shall not exceed 50  $\mu\text{s}$ .

#### A.1.2 Transmit power spectral density and aggregate power level

The power emitted by the ATU-R is limited by the specifications in this subclause. In addition, the ATU-R transmitter shall comply with national requirements on emission of electromagnetic energy.

##### A.1.2.1 All initialization signals (except R-ECT) starting with R-REVERB1

The nominal PSD in the band from 25.875 to 138 kHz shall be set at -38 dBm/Hz for a nominal transmit power not greater than 12.5 dBm. The reference PSD in the band from 25.875 to 138 kHz shall be  $(-38 - \text{Absolute Upstream Fast Retrain Power Cutback}) \text{ dBm/Hz}$  for a reference aggregate transmit power of not greater than  $(12.5 - \text{Absolute Upstream Fast Retrain Power Cutback}) \text{ dBm}$ .

During the R-REVERB and R-SEGUE signals, all subcarriers from index  $i$  to 31 shall be transmitted, with  $i$  vendor discretionary. However, at the vendor's discretion, one or more of these subcarriers may not be transmitted during the R-MEDLEY signal.

To allow for non-ideal transmit filter effects (e.g. passband ripple and transition band rolloff), the maximum transmit PSD shall be no more than 1 dB above the reference PSD level. The maximum transmit PSD shall therefore be no higher than  $(-37 - \text{Absolute Upstream Fast Retrain Power Cutback}) \text{ dBm/Hz}$ .

##### A.1.2.2 R-ECT

Because R-ECT is a vendor-defined signal, the PSD specification shall be interpreted only as a maximum. This maximum level is  $(-3 - 37 - \text{Absolute Upstream Fast Retrain Power Cutback}) \text{ dBm/Hz}$ .



Cutback) dBm/Hz for the band from 25.875 to 138 kHz. Subcarriers 1 to 5 may be used, but the power in these carriers shall conform to the specification give in A.1.

### A.1.2.3 Steady State data signal

The nominal PSD in the band from 25.875 to 138 kHz shall be set at  $-38$  dBm/Hz. The nominal aggregate power shall be set at  $-1.65 + 10\log(\text{ncup})$ , where  $\text{ncup}$  is the number of subcarriers used (i.e. with  $b_i > 0$ ) (12.5 dBm if all subcarriers are used). The reference PSD in the band from 25.875 to 138 kHz shall be  $(-38 - \text{Absolute Upstream Fast Retrain Power Cutback})$  dBm/Hz. The reference aggregate power shall be set at  $(-1.65 - \text{Absolute Upstream Fast Retrain Power Cutback} + 10\log(\text{ncup}))$ , where  $\text{ncup}$  is the number of subcarriers used (12.5 - Absolute Upstream Fast Retrain Power Cutback dBm if all subcarriers are used). The transmit PSD and aggregate power may, however, be changed from their reference values in either of the following circumstances:

- The bits and gains table received from the ATU-C during initialization and possibly updated through bit swaps, may not allocate bits to some subcarriers and may finely adjust (i.e. within a  $-14.5$  to  $+2.5$  dB range) the transmit PSD level of others in order to equalize expected error rates on each of those subcarriers.
- Vendor discretionary transmit PSD levels for unused subcarriers (i.e. with  $b_i = 0$ ). The maximum transmit PSD for these subcarriers is specified in b) and c) below.

To allow for non-ideal transmit filter effects (e.g. passband ripple and transition band rolloff), the maximum transmit PSD shall be no more than 1 dB above the finely adjusted reference PSD level. The maximum transmit PSD shall therefore be no higher than  $(-34.5 - \text{Absolute Upstream Fast Retrain Power Cutback})$  dBm/Hz.

The transmit PSD of each subcarrier is defined as follows:

- a) For the subcarriers with ( $b_i > 0$ ), the ATU-R transmitter shall transmit at PSD levels equal to that specified by the  $g_i$  (e.g.  $g_i = 1$ , then transmit at R-MEDLEY transmit PSD level). The aggregate transmit power in these subcarriers shall not exceed  $-1.65 + 10\log(\text{ncup}_1)$  dBm by more than 0.7 dB, where  $\text{ncup}_1$  is the number of these subcarriers (i.e. with  $b_i > 0$ ).
- b) For the subcarriers with ( $b_i = 0$  and  $g_i > 0$ ), the ATU-R transmitter should and is recommended to transmit at PSD levels equal to that specified by the  $g_i$  (e.g.  $g_i = 1$ , then transmit at R-MEDLEY level), with a 4-QAM constellation point (which may change from symbol to symbol). The ATU-R receiver cannot assume any particular PSD levels on those subcarriers. The transmit PSD levels of those subcarriers shall be no higher than the C-REVERB1 transmit PSD level +  $10\log(g_i^2)$  dB. The aggregate transmit power in these subcarriers shall not exceed  $-1.65 + 10\log(\text{ncup}_2)$  dBm, where  $\text{ncup}_2$  is the number of these subcarriers (i.e. with  $b_i = 0$  and  $g_i > 0$ ).
- c) For the subcarriers with ( $b_i = 0$  and  $g_i = 0$ ), the ATU-R transmitter should and is recommended to transmit no power on those subcarriers. The ATU-C receiver cannot assume any particular PSD level on those subcarriers. The transmit PSD levels of those subcarriers with  $g_i = 0$  shall be at least 10 dB below the sync symbol reference transmit PSD level if the subcarrier is below the lowest used subcarrier (lowest  $i$  with  $b_i > 0$ ) and shall be below the sync symbol reference transmit PSD level if the subcarrier is above the lowest used subcarrier.

The aggregate transmit power over the 25.875 to 138 kHz band shall be no higher than 12.5 dBm, which is equivalent to an average transmit PSD of no higher than  $-38$  dBm/Hz.

NOTE – It is recommended that the  $g_i$  values for subcarriers with  $g_i > 0$  are constrained within  $\pm 2.5$  dB with respect to  $g_{\text{sync}}$ , during initialization and subsequent bit swaps to avoid cyclostationary interference from the synchronization symbol.

#### A.1.2.4 Synchronization symbol

At Initialization, the sync symbol reference transmit PSD level shall be set at  $-38 - \text{Absolute Upstream Fast Retrain Power Cutback} + 10\log(g_{\text{sync}}^2)$  dBm/Hz, with  $g_{\text{sync}}^2$  defined as the average  $g_i^2$  value over the used (i.e.  $b_i > 0$ ) subcarriers. The sync symbol reference transmit PSD shall not be updated with user subcarrier gain changes during SHOWTIME.

The transmit PSD level for those subcarriers with  $g_i > 0$  shall be the sync symbol reference transmit PSD level. The transmit PSD levels of those subcarriers with  $g_i = 0$  shall be at least 10 dB below the sync symbol reference transmit PSD level if the subcarrier is below the lowest used subcarrier (lowest  $i$  with  $b_i > 0$ ) and shall be below the sync symbol reference transmit PSD level if the subcarrier is above the lowest used subcarrier.

Since the  $g_i$  are applied only to the data symbols, the transmit PSD of a synchronization symbol differs from the transmit PSD of a data symbol. These  $g_i$  are calculated for the multipoint constellations in order to equalize the expected error rate on all subcarriers, and are therefore irrelevant for most of the 4-QAM modulated subcarriers of the synchronization symbol.

#### A.2 ATU-C transmitter PSD mask

Figure A.2 shows the Power Spectral Density (PSD) mask for an ATU-C transmitter operating in non-overlapped spectrum mode. The low frequency stop band is defined as frequencies below 138 kHz. The high frequency stop band is defined as frequencies greater than 552 kHz. The slopes shown are approximate; refer to the equations for the exact slopes.

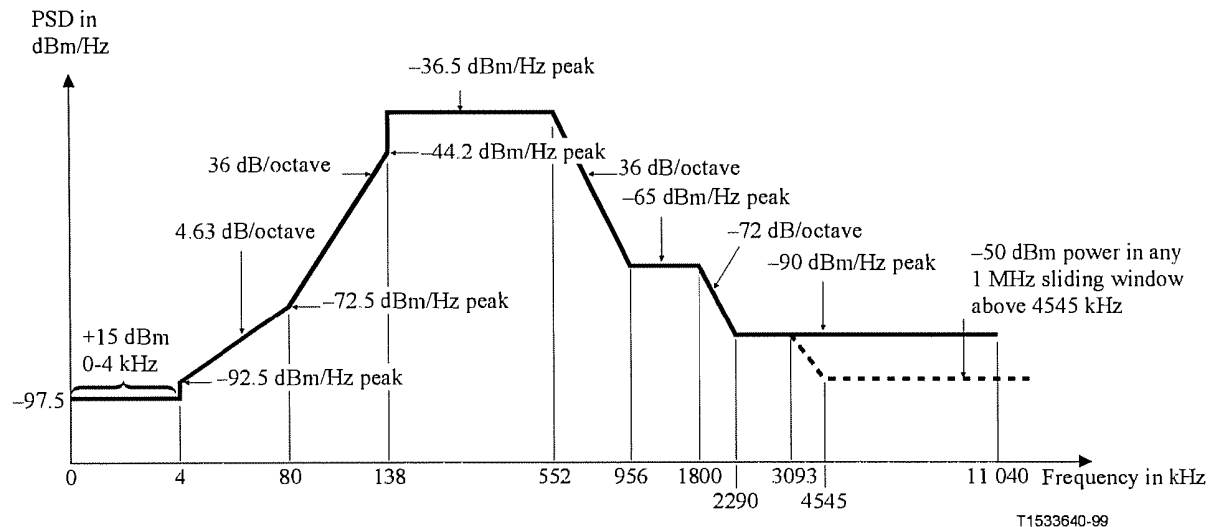


Figure A.2/G.992.2 – ATU-C transmitter PSD mask

Frequency band (kHz)	Equation for line (dBm/Hz)	Impedance (Ohm)	Resolution Bandwidth (kHz)
0-4	-97.5	100	
	with +15 dBm power in 0-4 kHz window	900	4
4-80	$-92.5 + 4.63 \times \log(f/4)/\log(2)$	100	
80-138	$-72.5 + 36 \times \log(f/80)/\log(2)$	100	10
138-552	-36.5	100	10
552-956	$-36.5 - 36 \times \log(f/552)/\log(2)$	100	10
956-1800	-65	100	10
1800-2290	$-65 - 72 \times \log(f/1800)/\log(2)$	100	10
2290-3093	-90	100	10
3093-4545	< -90 peak	100	10
	with max power in the $[f, f+1 \text{ MHz}]$ window of $(-36.5 - 36 \times \log(f/1104)/\log(2) + 60) \text{ dBm}$	100	1000
4545-11 040	< 90 peak	100	10
	with max power in the $[f, f+1 \text{ MHz}]$ window of -50 dBm	100	1000

#### A.2.1 Passband PSD ripple and group delay

The average PSD within the used passband shall be no greater than -36.5 dBm/Hz reduced by power cutback in steps of 2 dB. The lower end of the passband is implementation dependent. The upper end depends on whether the signal is for initialization (see A.2.2.1) or steady state (see A.2.2.3).

The passband ripple shall be no greater than +3.5 dB above the specified nominal level; the maximum PSD of  $(-40 - 2n + 3.5) \text{ dBm/Hz}$  applies across the whole band from 25 kHz to 552 kHz, where  $2n$  is defined in 11.7.5.

The group delay variation over the passband shall not exceed 50  $\mu\text{s}$ .

#### A.2.2 Transmit power spectral density and aggregate power level

The power emitted by the ATU-C is limited by the specifications in this subclause. In addition, the ATU-C transmitter shall comply with national requirements on emission of electromagnetic energy.

##### A.2.2.1 All initialization signals (except C-ECT) starting with C-REVERB1

The nominal PSD in the band from 138 to 552 kHz shall be set at -40 dBm/Hz for a nominal transmit power in the band not greater than 16.2 dBm. In the other frequency bands the nominal PSD shall not exceed the mask represented in Figure A.2. The reference PSD in the band from 138 to 552 kHz shall be set at  $(-40 - 2n) \text{ dBm/Hz}$  for reference transmit power in that band not greater than  $16.2 - 2n \text{ dBm}$ , with  $2n$  as defined in 11.7.5. In the other frequency bands the reference PSD shall not exceed the mask represented in Figure A.2 reduced by  $2n$ .

During the C-REVERB and C-SEGUE signals, all subcarriers from index  $i$  to 127 shall be transmitted, with vendor discretion. However, at the vendor's discretion, one or more of these subcarriers may not be transmitted during the C-MEDLEY signal.

To allow for non-ideal transmit filter effects (e.g. passband ripple and transition band rolloff), the maximum transmit PSD shall be no more than 1 dB above the nominal PSD level. The maximum transmit PSD shall therefore be no higher than  $-39 - 2n \text{ dBm/Hz}$ .

**A.2.2.2 C-ECT**

Because C-ECT is a vendor-defined signal, the PSD specification shall be interpreted only as a maximum. This maximum level is  $-39 - 2n$  dBm/Hz for the band from 138 to 552 kHz. Subcarriers 1 to 31 may be used, but the power in these carriers shall conform to the specification given in A.2.

**A.2.2.3 Steady-state data signal**

The nominal PSD in the band from 138 to 552 kHz shall be set at  $-40$  dBm/Hz. The nominal aggregate power shall be set at  $-3.65 + 10\log(nc_{\text{down1}})$ , where  $nc_{\text{down1}}$  is the number of subcarriers used (i.e. with  $b_i > 0$ ) (16.2 dBm if all subcarriers are used). The reference PSD in the band from 138 to 552 kHz shall be set at  $(-40 - 2n)$  dBm/Hz, where  $2n$  is defined in 11.7.5. The transmit PSD and aggregate power may, however, be changed from their reference values in either of the following circumstances:

- The bits and gains table (received from the ATU-R during initialization and possibly updated through bit swaps, may not allocate bits to some subcarriers and may finely adjust (i.e. within a  $-14.5$  to  $+2.5$  dB range) the transmit PSD level of others in order to equalize expected error rates on each of those subcarriers.
- Vendor-discretionary transmit PSD levels for unused subcarriers (i.e. with  $b_i = 0$ ). The maximum transmit PSD for these subcarriers is specified in b) and c) below.

To allow for non-ideal transmit filter effects (e.g. passband ripple and transition band rolloff), the maximum transmit PSD shall be no more than 1 dB above the finely adjusted reference PSD level. The maximum transmit PSD shall therefore be no higher than  $-36.5 - 2n$  dBm/Hz.

The transmit PSD of each subcarrier is defined as follows:

- For the subcarriers with ( $b_i > 0$ ), the ATU-C transmitter shall transmit at PSD levels equal to that specified by the  $g_i$  (e.g.  $g_i = 1$ , then transmit at C-MEDLEY transmit PSD level). The aggregate transmit power in these subcarriers shall not exceed  $-3.65 + 10\log(nc_{\text{down1}}) - 2n$  dBm by more than 0.7 dB, where  $nc_{\text{down1}}$  is the number of these subcarriers (i.e. with  $b_i > 0$ ).
- For the subcarriers with ( $b_i = 0$  and  $g_i > 0$ ), the ATU-C transmitter should and is recommended to transmit at PSD levels equal to that specified by the  $g_i$  (e.g.  $g_i = 1$ , then transmit at C-MEDLEY level), with a 4-QAM constellation point (which may change from symbol to symbol). The ATU-R receiver cannot assume any particular PSD levels on those subcarriers. The transmit PSD levels of those subcarriers shall be no higher than the C-REVERB1 transmit PSD level +  $10\log(g_i^2)$  dB. The aggregate transmit power in these subcarriers shall not exceed  $-3.65 + 10\log(nc_{\text{down2}}) - 2n$  dBm, where  $nc_{\text{down2}}$  is the number of these subcarriers (i.e. with  $b_i = 0$  and  $g_i > 0$ ).
- For the subcarriers with ( $b_i = 0$  and  $g_i = 0$ ), the ATU-C transmitter should and is recommended to transmit no power on those subcarriers. The ATU-R receiver cannot assume any particular PSD level on those subcarriers. The transmit PSD levels of those subcarriers with  $g_i = 0$  shall be at least 10 dB below the sync symbol reference transmit PSD level if the subcarrier is below the lowest used subcarrier (lowest  $i$  with  $b_i > 0$ ) and shall be below the sync symbol reference transmit PSD level if the subcarrier is above the lowest used subcarrier.

The aggregate transmit power over the 138 to 552 kHz band shall be no higher than  $16.2 - 2n$  dBm, which is equivalent to an average transmit PSD of no higher than  $-40 - 2n$  dBm/Hz (with  $n$  indicating power cutback,  $n = 0$  to 6).

NOTE – It is recommended that the  $g_i$  values for subcarriers with  $g_i > 0$  are constrained within  $\pm 2.5$  dB with respect to  $g_{\text{sync}}$ , during initialization and subsequent bitstreams to avoid cyclostationary interference from the synchronization symbol.

#### A.2.2.4 Synchronization symbol

At Initialization, the sync symbol reference transmit PSD level shall be set at  $-40 - 2n + 10\log(g_{\text{sync}}^2)$  dBm/Hz, with  $g_{\text{sync}}^2$  defined as the average  $g_i^2$  value over the used (i.e.  $b_i > 0$ ) subcarriers. The sync symbol reference transmit PSD shall not be updated with used subcarrier gain changes during SHOWTIME.

The transmit PSD level for those subcarriers with  $g_i > 0$  shall be sync symbol reference transmit PSD level. The transmit PSD levels of those subcarriers with  $g_i = 0$  shall be at least 10 dB below the sync symbol reference transmit PSD level if the subcarrier is below the lowest used subcarrier (lowest  $i$  with  $b_i > 0$ ) and shall be below the sync symbol reference transmit PSD level if the subcarrier is above the lowest used subcarrier.

Since the  $g_i$  are applied only to the data symbols, the transmit PSD of a synchronization symbol differs from the transmit PSD of a data symbol. These  $g_i$  are calculated for the multipoint constellations in order to equalize the expected error rate on all subcarriers, and are therefore irrelevant for most of the 4-QAM modulated subcarriers of the synchronization symbol.

## ANNEX B

### Overlapped spectrum operation

#### B.1 ATU-R transmitter PSD mask

Figure B.1 shows the Power Spectral Density (PSD) mask for an ATU-R transmitter operating in overlapped spectrum mode. The low frequency stop band is defined as the voice band. The high frequency stop band is defined as frequencies greater than 138 kHz. The slopes shown are approximate; refer to the equations for the exact slopes.

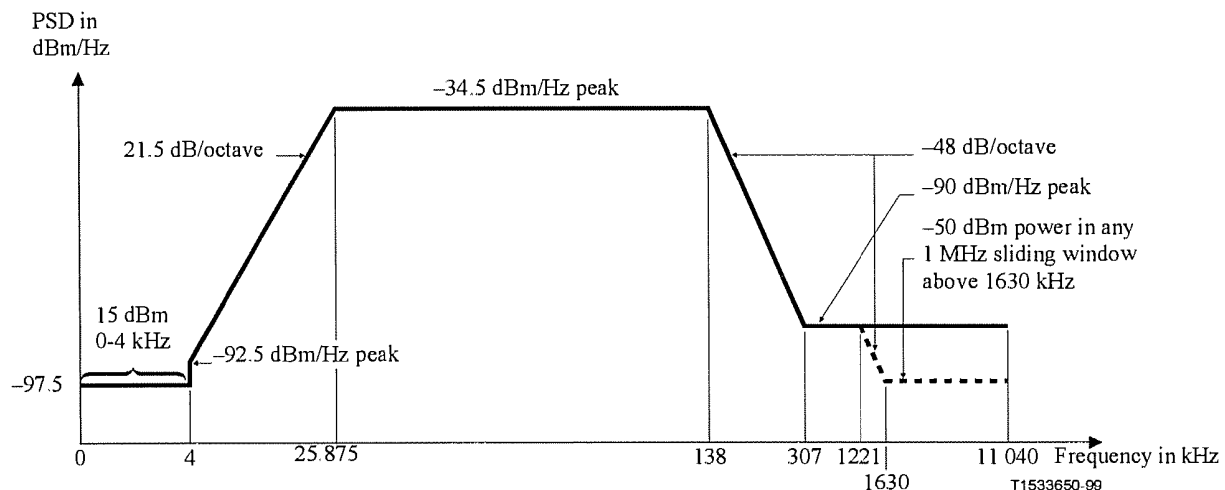


Figure B.1/G.992.2 – ATU-R transmitter PSD mask



Frequency band (kHz)	Equation for line (dBm/Hertz)	Impedance (Ohm)	Resolution bandwidth (kHz)
0-4	-97.5	100	
	with +15 dBm power in 0-4 kHz window	600	4
>4-25.875	$-92.5 + 21.5 \times \log(f/4)/\log(2)$	100	
25.875-138	-34.5	100	10
138-307	$-34.5 - 48 \times \log(f/138)/\log(2)$	100	10
307-1221	-90	100	10
1221-1630	< -90 peak	100	10
	with max power in the $[f, f+1 \text{ MHz}]$ window of $(-90 - 48 \times \log(f/1221)/\log(2) + 60) \text{ dBm}$	100	1000
1630-11 040	< -90 peak	100	10
	with max power in the $[f, f+1 \text{ MHz}]$ window of -50 dBm	100	1000

### B.1.1 Passband PSD ripple and group delay

The average PSD within the used passband shall be no greater than -38 dBm/Hz reduced by power cutback in steps of 2 dB. The lower end of the passband is implementation dependent. The upper end of the passband depends on whether the signal is for initialization (see B.1.2.1) or steady state (see B.1.2.3).

The passband ripple shall be no greater than +3.5 dB above the specified reference level; the maximum PSD  $(-38 - \text{Absolute Upstream Fast Retrain Power Cutback} + 3.5) \text{ dBm/Hz}$  applies across the whole band from 25.875 kHz to 138 kHz.

The group delay variation over the passband shall not exceed 50  $\mu\text{s}$ .

### B.1.2 Transmit power spectral density and aggregate power level

The power emitted by the ATU-R is limited by the specifications in this subclause. In addition, the ATU-R transmitter shall comply with national requirements on emission of electromagnetic energy.

#### B.1.2.1 All initialization signals (except R-ECT) starting with R-REVERB1

The nominal PSD in the band from 25.875 to 138 kHz shall be set at -38 dBm/Hz for a nominal transmit power not greater than 12.5 dBm. The reference PSD in the band from 25.875 to 138 kHz shall be  $(-38 - \text{Absolute Upstream Fast Retrain Power Cutback}) \text{ dBm/Hz}$  for a reference aggregate transmit power of not greater than  $(12.5 - \text{Absolute Upstream Fast Retrain Power Cutback}) \text{ dBm}$ .

During the R-REVERB and R-SEGUE signals, all subcarriers from index  $i$  to 31 shall be transmitted, with  $i$  vendor discretionary. However, at the vendor's discretion, one or more of these subcarriers may not be transmitted during the R-MEDLEY signal.

To allow for non-ideal transmit filter effects (e.g. passband ripple and transition band rolloff), the maximum transmit PSD shall be no more than 1 dB above the reference PSD level. The maximum transmit PSD shall therefore be no higher than  $(-37 - \text{Absolute Upstream Fast Retrain Power Cutback}) \text{ dBm/Hz}$ .

#### B.1.2.2 R-ECT

Because R-ECT is a vendor-defined signal, the PSD specification shall be interpreted only as a maximum. This maximum level is  $(-37 - \text{Absolute Upstream Fast Retrain Power Cutback}) \text{ dBm/Hz}$ .

for the band from 25.875 to 138 kHz. Subcarriers 1 to 5 may be used, but the power in these carriers shall conform to the specification given in A.1.

### B.1.2.3 Steady State data signal

The nominal PSD in the band from 25.875 to 138 kHz shall be set at  $-38$  dBm/Hz. The nominal aggregate power shall be set at  $-1.65 + 10\log(\text{ncup})$ , where  $\text{ncup}$  is the number of subcarriers used (i.e. with  $b_i > 0$ ) (12.5 dBm if all subcarriers are used). The reference PSD in the band from 25.875 to 138 kHz shall be  $(-38 - \text{Absolute Upstream Fast Retrain Power Cutback})$  dBm/Hz. The reference aggregate power shall be set at  $(-1.65 - \text{Absolute Upstream Fast Retrain Power Cutback} + 10\log(\text{ncup}))$ , where  $\text{ncup}$  is the number of subcarriers used (12.5 – Absolute Upstream Fast Retrain Power Cutback dBm if all subcarriers are used). The transmit PSD and aggregate power may, however, be changed from their nominal values in either of the following circumstances:

- The bits and gains table (received from the ATU-C during initialization and possibly updated through bit swaps, (see R-B&G in TBD) may not allocate bits to some subcarriers and may finely adjust (i.e. within a  $-14.5$  to  $+2.5$  dB range) the transmit PSD level of others in order to equalize expected error rates on each of those subcarriers.
- Vendor-discretionary transmit PSD levels for unused subcarriers (i.e. with  $b_i = 0$ ). The maximum transmit PSD for these subcarriers is specified in b) and c) below.

To allow for non-ideal transmit filter effects (e.g. passband ripple and transition band rolloff), the maximum transmit PSD shall be no more than 1 dB above the finely adjusted nominal PSD level. The maximum transmit PSD shall therefore be no higher than  $(-34.5 - \text{Absolute Upstream Fast Retrain Power Cutback})$  dBm/Hz.

The transmit PSD of each subcarrier is defined as follows:

- a) For the subcarriers with ( $b_i > 0$ ), the ATU-R transmitter shall transmit at PSD levels equal to that specified by the  $g_i$  (e.g.  $g_i = 1$ , then transmit at R-MEDLEY transmit PSD level). The aggregate transmit power in these subcarriers shall not exceed  $-1.65 + 10\log(\text{ncup}_1)$  dBm by more than 0.7 dB, where  $\text{ncup}_1$  is the number of these subcarriers (i.e. with  $b_i > 0$ ).
- b) For the subcarriers with ( $b_i = 0$  and  $g_i > 0$ ), the ATU-R transmitter should and is recommended to transmit at PSD levels equal to that specified by the  $g_i$  (e.g.  $g_i = 1$ , then transmit at R-MEDLEY level), with a 4-QAM constellation point (which may change from symbol to symbol). The ATU-R receiver cannot assume any particular PSD levels on those subcarriers. The transmit PSD levels of those subcarriers shall be no higher than the R-REVERB1 transmit PSD level +  $10\log(g_i^2)$  dB. The aggregate transmit power in these subcarriers shall not exceed  $-1.65 + 10\log(\text{ncup}_2)$  dBm, where  $\text{ncup}_2$  is the number of these subcarriers (i.e. with  $b_i = 0$  and  $g_i > 0$ ).
- c) For the subcarriers with ( $b_i = 0$  and  $g_i = 0$ ), the ATU-R transmitter should and is recommended to transmit no power on those subcarriers. The ATU-C receiver cannot assume any particular PSD level on those subcarriers. The transmit PSD levels of those subcarriers with  $g_i = 0$  shall be at least 10 dB below the sync symbol reference transmit PSD level if the subcarrier is below the lowest used subcarrier (lowest  $i$  with  $b_i > 0$ ) and shall be below the sync symbol reference transmit PSD level if the subcarrier is above the lowest used subcarrier.

The aggregate transmit power over the 25.875 to 138 kHz band shall be no higher than 12.5 dBm, which is equivalent to an average transmit PSD of no higher than  $-38$  dBm/Hz.

NOTE – It is recommended that the  $g_i$  values for subcarriers with  $g_i > 0$  are constrained within  $\pm 2.5$  dB with respect to  $g_{\text{sync}}$ , during initialization and subsequent bitswaps to avoid cyclostationary interference from the synchronization symbol.

### B.1.2.4 Synchronization symbol

At Initialization, the sync symbol reference transmit PSD level shall be set at  $-38 - \text{Absolute Upstream Fast Retrain Power Cutback} + 10\log(g_{\text{sync}}^2)$  dBm/Hz, with  $g_{\text{sync}}^2$  defined as the average  $g_i^2$  value over the used (i.e.  $b_i > 0$ ) subcarriers. The sync symbol reference transmit PSD shall not be updated with user subcarrier gain changes during SHOWTIME.

The transmit PSD level for those subcarriers with  $g_i > 0$  shall be the sync symbol reference transmit PSD level. The transmit PSD levels of those subcarriers with  $g_i = 0$  shall be at least 10 dB below the sync symbol reference (i.e. nominally  $-38 - \text{Absolute Upstream Fast Retrain Power Cutback}$ ) transmit PSD level if the subcarrier is below the lowest used subcarrier (lowest  $i$  with  $b_i > 0$ ) and shall be below the sync symbol reference transmit PSD level if the subcarrier is above the lowest used subcarrier.

Since the  $g_i$  are applied only to the data symbols, the transmit PSD of a synchronization symbol differs from the transmit PSD of a data symbol. These  $g_i$  are calculated for the multipoint constellations in order to equalize the expected error rate on all subcarriers, and are therefore irrelevant for most of the 4-QAM modulated subcarriers of the synchronization symbol.

## B.2 ATU-C transmitter PSD mask

Figure B.2 shows the power spectral density (PSD) mask for an ATU-C transmitter operating in overlapped spectrum mode. The low frequency stop band is defined the voice band. The high frequency stop band is defined as frequencies greater than 552 kHz. The slopes shown are approximate; refer to the equations for the exact slopes.

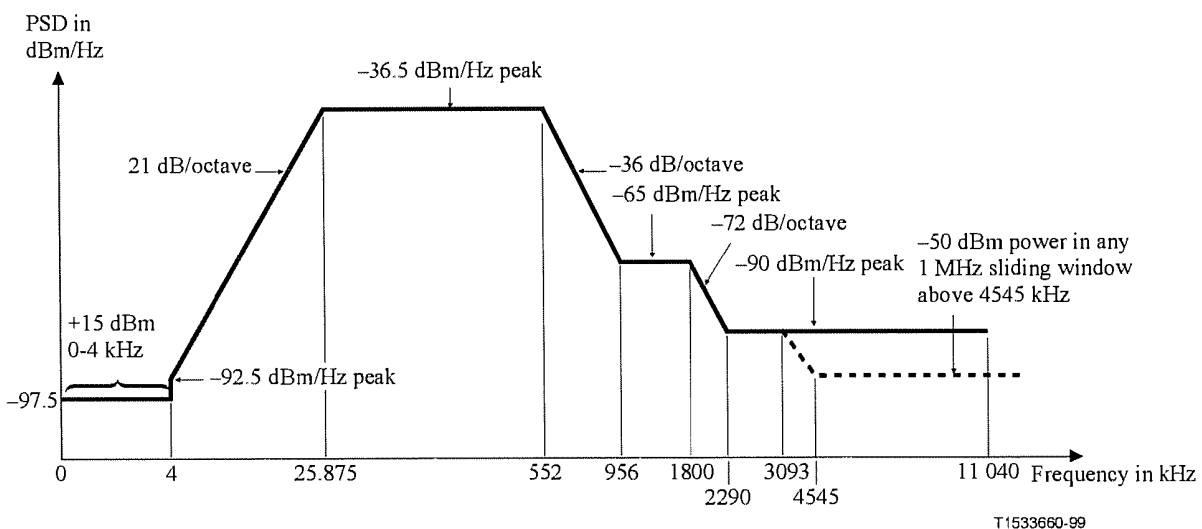


Figure B.2/G.992.2 – ATU-C transmitter PSD mask

Frequency band (kHz)	Equation for line (dBm/Hz)	Impedance (Ohm)	Resolution Bandwidth (kHz)
0-4	-97.5	100	4
	with +15 dBm power in 0-4 kHz window	900	
>4-25.875	$-92.5 + 21.5 \times \log(f/4)/\log(2)$	100	
25.875-552	-34.5	100	10
552-956	$-36.5 - 36 \times \log(f/552)/\log(2)$	100	10
956-1800	-65	100	10
1800-2290	$-65 - 72 \times \log(f/1800)/\log(2)$	100	10
2290-3093	-90	100	10
3093-4545	< -90 peak	100	10
	with max power in the $[f, f+1 \text{ MHz}]$ window of $(-36.5 - 36 \times \log(f/1104)/\log(2) + 60)$ dBm	100	1000
4545-11 040	< -90 peak	100	10
	with max power in the $[f, f+1 \text{ MHz}]$ window of -50 dBm	100	1000

### B.2.1 Passband PSD ripple and group delay

The average PSD within the used passband shall be no greater than -36.5 dBm/Hz reduced by power cutback in steps of 2 dB. The lower end of the passband is implementation dependent. The upper end depends on whether the signal is for initialization (see B.2.2.1) or steady state (see B.2.2.3).

The passband ripple shall be no greater than +3.5 dB above the specified nominal level; the maximum PSD of  $(-40 - 2n + 3.5)$  dBm/Hz applies across the whole band from 25 kHz to 552 kHz where  $2n$  is defined in 11.7.5.

The group delay variation over the pass band shall not exceed 50  $\mu$ s.

### B.2.2 Transmit power spectral density and aggregate power level

The power emitted by the ATU-C is limited by the specifications in this subclause. In addition, the ATU-C transmitter shall comply with national requirements on emission of electromagnetic energy.

#### B.2.2.1 All initialization signals (except C-ECT) starting with C-REVERB1

The nominal PSD in the band from 25.875 to 552 kHz shall be set at -40 dBm/Hz for a nominal aggregate transmit power not greater than 17.2 dBm. The reference PSD in the band from 138 to 552 kHz shall be set at  $(-40 - 2n)$  dBm/Hz for reference aggregate transmit power not greater than  $16.2 - 2n$  dBm, with  $2n$  as defined in 11.7.5

During the C-REVERB and C-SEGUE signals, all subcarriers from index  $i$  to 127 shall be transmitted, with  $i$  vendor discretionary. However, at the vendor's discretion, one or more of these subcarriers may not be transmitted during the C-MEDLEY signal.

To allow for non-ideal transmit filter effects (e.g. passband ripple and transition band rolloff), the maximum transmit PSD shall be no more than 1 dB above the nominal PSD level. The maximum transmit PSD shall therefore be no higher than  $-39 - 2n$  dBm/Hz.

#### B.2.2.2 C-ECT

Because C-ECT is a vendor-defined signal, the PSD specification shall be interpreted only as a maximum. This maximum level is  $-39 - 2n$  dBm/Hz for the band from 25.875 to 552 kHz.

Subcarriers 1 to 5 may be used, but the power in these carriers shall conform to the specification given in B.2.

### B.2.2.3 Steady-state data signal

The nominal PSD in the band from 25.875 to 552 kHz shall be set at  $-40$  dBm/Hz. The nominal aggregate power shall be set at  $-3.65 + 10\log(nc_{\text{down}})$ , where  $nc_{\text{down}}$  is the number of subcarriers used (i.e. with  $b_i > 0$ ) (17.2 dBm if all subcarriers are used). The reference PSD in the band from 138 to 552 kHz shall be set at  $(-40 - 2n)$  dBm/Hz, where  $2n$  is defined in 11.7.5. The transmit PSD and aggregate power may, however, be changed from their reference values in either of the following circumstances:

- The bits and gains table (received from the ATU-R during initialization and possibly updated through bit swaps may not allocate bits to some subcarriers and may finely adjust (i.e. within a  $-14.5$  to  $+2.5$  dB range) the transmit PSD level of others in order to equalize expected error rates on each of those subcarriers.
- Vendor-discretionary transmit PSD levels for unused subcarriers (i.e. with  $b_i = 0$ ). The maximum transmit PSD for these subcarriers is specified in b) and c) below.

To allow for non-ideal transmit filter effects (e.g. passband ripple and transition band rolloff), the maximum transmit PSD shall be no more than 1 dB above the finely adjusted reference PSD level. The maximum transmit PSD shall therefore be no higher than  $-36.5 - 2n$  dBm/Hz.

The transmit PSD of each subcarrier is defined as follows:

- For the subcarriers with ( $b_i > 0$ ), the ATU-C transmitter shall transmit at PSD levels equal to that specified by the  $g_i$  (e.g.  $g_i = 1$ , then transmit at C-MEDLEY transmit PSD level). The aggregate transmit power in these subcarriers shall not exceed  $-3.65 + 10\log(nc_{\text{down}1}) - 2n$  dBm by more than 0.7 dB, where  $nc_{\text{down}1}$  is the number of these subcarriers (i.e. with  $b_i > 0$ ).
- For the subcarriers with ( $b_i = 0$  and  $g_i > 0$ ), the ATU-C transmitter should and is recommended to transmit at PSD levels equal to that specified by the  $g_i$  (e.g.  $g_i = 1$ , then transmit at C-MEDLEY level), with a 4-QAM constellation point (which may change from symbol to symbol). The ATU-R receiver cannot assume any particular PSD levels on those subcarriers. The transmit PSD levels of those subcarriers shall be no higher than the C-REVERB1 transmit PSD level +  $10\log(g_i^2)$  dB. The aggregate transmit power in these subcarriers shall not exceed  $-3.65 + 10\log(nc_{\text{down}2}) - 2n$  dBm, where  $nc_{\text{down}2}$  is the number of these subcarriers (i.e. with  $b_i = 0$  and  $g_i > 0$ ).
- For the subcarriers with ( $b_i = 0$  and  $g_i = 0$ ), the ATU-R transmitter should and is recommended to transmit no power on those subcarriers. The ATU-C receiver cannot assume any particular PSD level on those subcarriers. The transmit PSD levels of those subcarriers with  $g_i = 0$  shall be at least 10 dB below the sync symbol reference transmit PSD level if the subcarrier is below the lowest used subcarrier (lowest  $i$  with  $b_i > 0$ ) and shall be below the sync symbol reference transmit PSD level if the subcarrier is above the lowest used subcarrier.

The aggregate transmit power over the 138 to 552 kHz band shall be no higher than  $16.2 - 2n$  dBm, which is equivalent to an average transmit PSD of no higher than  $-40 - 2n$  dBm/Hz (with  $n$  indicating power cutback,  $n = 0$  to 6).

NOTE – It is recommended that the  $g_i$  values for subcarriers with  $g_i > 0$  are constrained within  $\pm 2.5$  dB with respect to  $g_{\text{sync}}$ , during initialization and subsequent bitswaps to avoid cyclostationary interference from the synchronization symbol.



**B.2.2.4 Synchronization symbol**

At Initialization, the sync symbol reference transmit PSD level shall be set at  $-40 - 2n + 10\log(g_{\text{sync}}^2)$  dBm/Hz, with  $g_{\text{sync}}^2$  defined as the average  $g_i^2$  value over the used (i.e.  $b_i > 0$ ) subcarriers. The sync symbol reference transmit PSD shall not be updated with used subcarrier gain changes during SHOWTIME.

The transmit PSD level for those subcarriers with  $g_i > 0$  shall be the sync symbol reference transmit PSD level. The transmit PSD levels of those subcarriers with  $g_i = 0$  shall be at least 10 dB below the sync symbol reference transmit PSD level if the subcarrier is below the lowest used subcarrier (lowest  $i$  with  $b_i > 0$ ) and shall be below the sync symbol reference transmit PSD level if the subcarrier is above the lowest used subcarrier.

Since the  $g_i$  are applied only to the data symbols, the transmit PSD of a synchronization symbol differs from the transmit PSD of a data symbol. These  $g_i$  are calculated for the multipoint constellations in order to equalize the expected error rate on all subcarriers, and are therefore irrelevant for most of the 4-QAM modulated subcarriers of the synchronization symbol.

**ANNEX C****ADSL above POTS co-existing in the same binder as TCM-ISDN DSL****C.1 Scope**

This annex describes those specifications that are unique to an ADSL system co-existing in the same binder as TCM-ISDN as defined in Appendix III/G.961. The subclauses in this annex provide the additions and modifications to the corresponding clauses in the main body. The modifications described in this annex provide a performance improvement over the Splitterless ADSL system specified in main body in an environment co-existing with TCM-ISDN. It is preferred that ADSL system implementing this annex also implements the main body.

**C.2 Definitions and abbreviations****C.2.1 Definitions**

**C.2.1.1 Dual Bitmap:** The Dual Bitmap method has dual bit rates under the FEXT and NEXT noise from TCM-ISDN.

**C.2.1.2 FEXT Bitmap:** Similar to the Dual Bitmap method; however, transmission only occurs during FEXT noise from TCM-ISDN.

**C.2.1.3 Hyperframe:** Five Superframes structure which synchronized TTR.

**C.2.1.4 Bitmap-F<sub>R</sub>:** ATU-C transmitter bitmap under TCM-ISDN FEXT noise generated at ATU-R.

**C.2.1.5 Bitmap-N<sub>R</sub>:** ATU-C transmitter bitmap under TCM-ISDN NEXT noise generated at ATU-R.

**C.2.1.6 Bitmap-F<sub>C</sub>:** ATU-R transmitter bitmap under TCM-ISDN FEXT noise generated at ATU-C.

**C.2.1.7 Bitmap-N<sub>C</sub>:** ATU-R transmitter bitmap under TCM-ISDN NEXT noise generated at ATU-C.

**C.2.1.8 FEXT<sub>R</sub> duration:** TCM-ISDN FEXT duration at ATU-R estimated by the ATU-C.

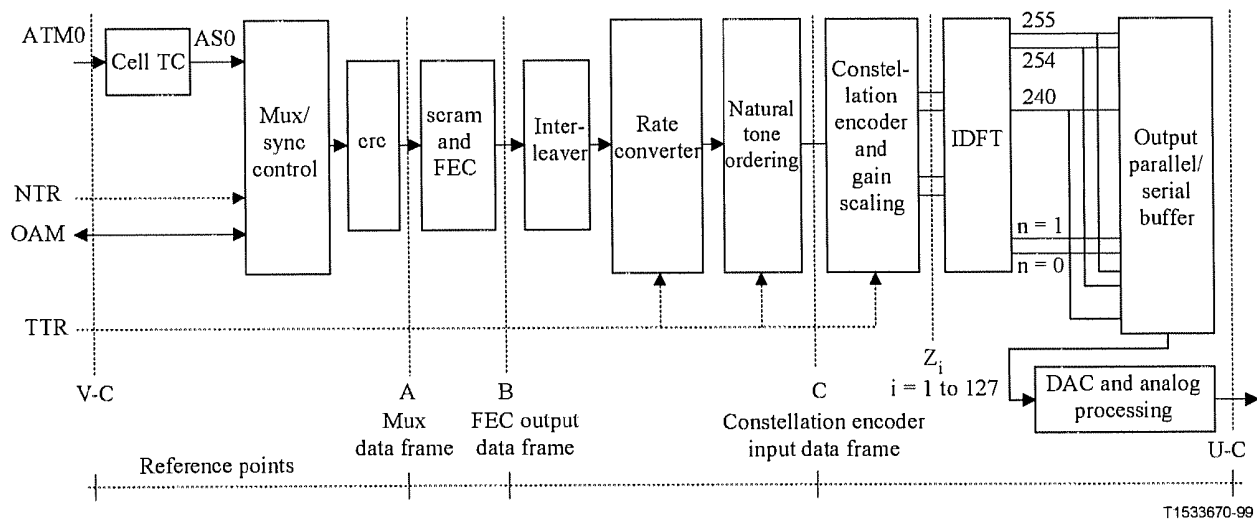
- C.2.1.9**     **NEXT<sub>R</sub> duration:** TCM-ISDN NEXT duration at ATU-R estimated by the ATU-C.
- C.2.1.10**   **FEXT<sub>C</sub> duration:** TCM-ISDN FEXT duration at ATU-C estimated by the ATU-R.
- C.2.1.11**   **NEXT<sub>C</sub> duration:** TCM-SDN NEXT duration at ATU-C estimated by the ATU-R.
- C.2.1.12**   **FEXT<sub>R</sub> symbol:** DMT symbol transmitted by ATU-C during TCM-ISDN FEXT.
- C.2.1.13**   **NEXT<sub>R</sub> symbol:** DMT symbol transmitted by ATU-C during TCM-ISDN NEXT.
- C.2.1.14**   **FEXT<sub>C</sub> symbol:** DMT symbol transmitted by ATU-R during TCM-ISDN FEXT.
- C.2.1.15**   **NEXT<sub>C</sub> symbol:** DMT symbol transmitted by ATU-R during TCM-ISDN NEXT.
- C.2.1.16**   **N<sub>SWF</sub>:** Sliding window frame counter.

## C.2.2 Abbreviations

TTR	TCM- ISDN Timing Reference
TTR <sub>C</sub>	Timing Reference used in ATU-C
TTR <sub>R</sub>	Timing Reference used in ATU-R
UI	Unit Interval

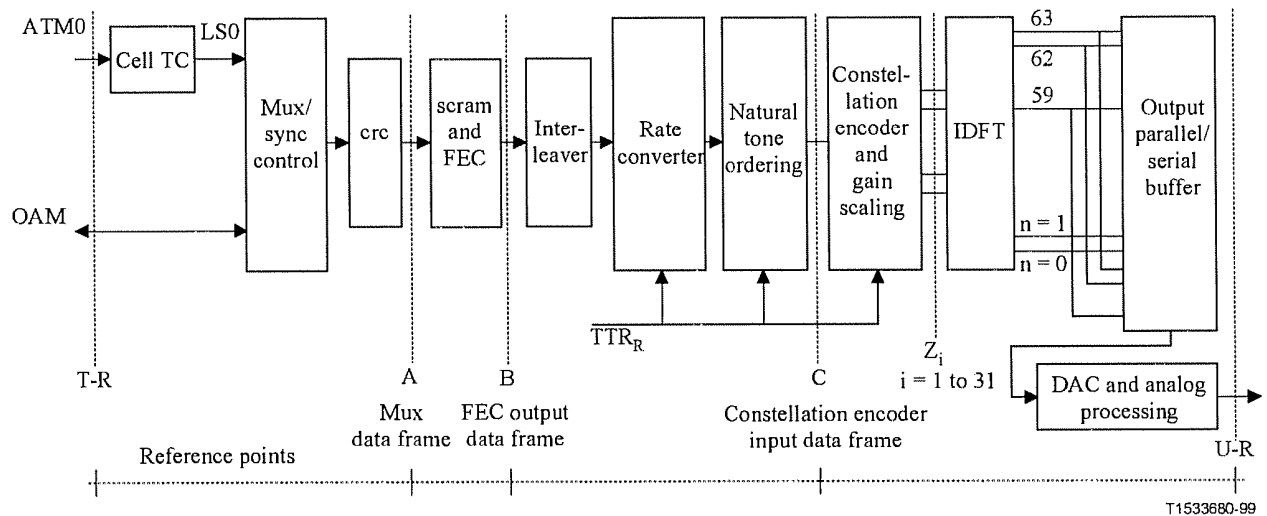
## C.3 Reference models

### C.3.1 ATU-C transmitter reference model (replaces figure in 4.2)



NOTE – The TTR may be generated in the ATU-C without being provided from the V-C reference point TCM-ISDN clock.

**Figure C.1/G.992.2 – ATU-C transmitter reference model for ATM transport**

**C.3.2 ATU-R transmitter reference model (replaces figure in 4.2)**

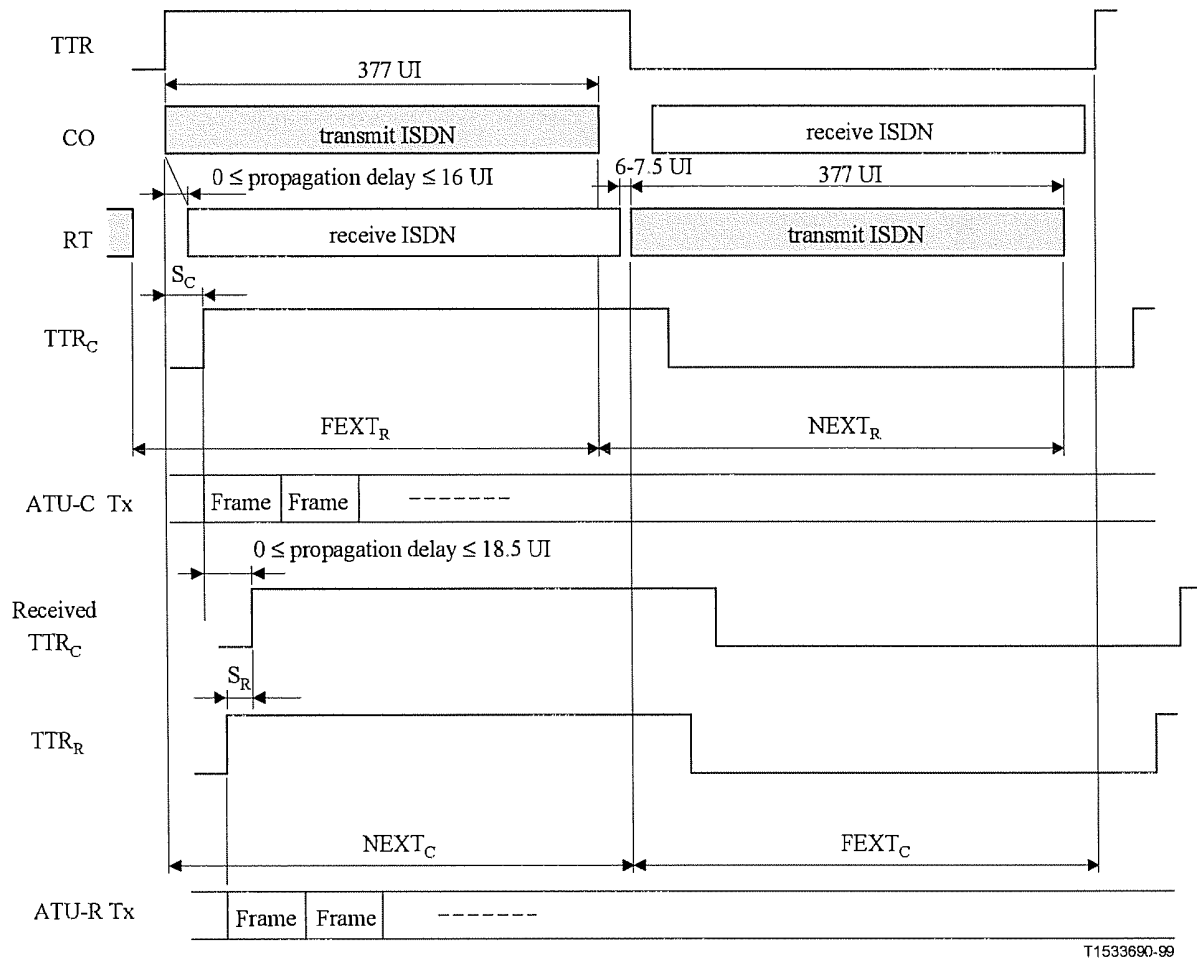
NOTE – The  $TTR_R$  shall be generated in the ATU-R from the received  $TTR_C$ , and shall be locked to 690 periods of upstream sampling clock (276 kHz).

**Figure C.2/G.992.2 – ATU-R transmitter reference model for ATM transport**

### C.3.3 ATU transmitter timing model (new)

#### C.3.3.1 TCM-ISDN crosstalk timing model (new)

Figure C.3 shows the timing chart of the crosstalk from TCM-ISDN.



T1533690-99

1 UI = 3.125 μs

FEXT<sub>R</sub> and NEXT<sub>R</sub> are estimated by the ATU-C

FEXT<sub>C</sub> and NEXT<sub>C</sub> are estimated by the ATU-R

TTR TCM-ISDN Timing reference

TTR<sub>C</sub> Timing reference used in ATU-C

Received TTR<sub>C</sub> Received TTR<sub>C</sub> at ATU-R

TTR<sub>R</sub> Timing reference used in ATU-R

S<sub>C</sub> 55 × 0.9058 μs: Offset from TTR to TTR<sub>C</sub>

S<sub>R</sub> -42 × 0.9058 μs: Offset from received TTR<sub>C</sub> to TTR<sub>R</sub>

**Figure C.3/G.992.2 – Timing chart of the TCM-ISDN cross-talk**

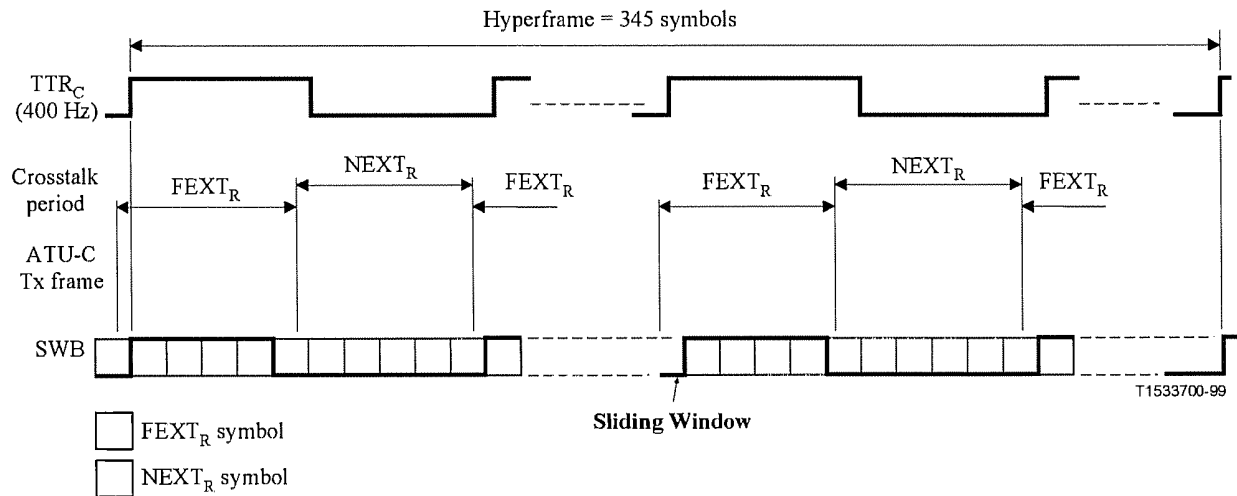
The data stream of TCM-ISDN transmitted in a TTR period. The TCM-ISDN CO transmits the symbols in the first half of the TTR period and the TCM-ISDN RT transmits in the second half of the TTR period. The ATU-C receives NEXT noise from ISDN in the first half of the TTR period and FEXT noise from ISDN in the second half of the TTR period. On the other hand, the ATU-R receives FEXT noise from the TCM-ISDN in the first half of the TTR period and NEXT noise from the ISDN in the second half of the TTR period.

As defined in C.5.2.2 and in C.8, the ATU-C shall estimate the  $FEXT_R$  and  $NEXT_R$  duration at ATU-R, and ATU-R shall estimate  $FEXT_C$  and  $NEXT_C$  duration at ATU-C taking propagation delay on the subscriber line into consideration.

The ATU-C shall transmit any symbol by synchronizing with the  $TTR_C$ . The ATU-R shall transmit any symbol by synchronizing with the  $TTR_R$  generated from received  $TTR_C$ .

### C.3.3.2 Sliding Window (new)

Figure C.4 shows the timing chart of the downstream transmission.



**Figure C.4/G.992.2 – Sliding Window**

The "Sliding Window" operation defines the procedures to transmit symbols under the crosstalk noise environment synchronized to the period of the TTR. The  $FEXT_{C/R}$  symbol represents the symbol completely inside the  $FEXT_{C/R}$  duration. The  $NEXT_{C/R}$  symbol represents the symbol containing any  $NEXT_{C/R}$  duration. Thus, there are more  $NEXT_{C/R}$  symbols than  $FEXT_{C/R}$  symbols.

The ATU-C decides which transmission symbol is a  $FEXT_R$  or  $NEXT_R$  symbol according to the Sliding Window and transmits it with the corresponding bit table. Similarly, ATU-R decides which transmission symbol is a  $FEXT_C$  or  $NEXT_C$  and transmits it with the corresponding bit table. Although the phase of the Sliding Window is asynchronous with the  $TTR_{C/R}$ , the pattern is fixed to the 345 frames of the hyperframe (see C.5.2.2).

### C.3.3.3 ATU-C symbol synchronization to TTR<sub>C</sub> (new)

The time duration of 345 symbols is equal to 34 cycles of  $TTR_C$  (or 32 cycles of  $TTR_C$  for symbols without a cyclic prefix). This implies a PLL lock at the ATU-R.

### C.3.3.4 Dual Bitmap switching (new)

The ATU-C transmits  $FEXT_R$  symbols using Bitmap- $F_R$  (in  $FEXT_R$  duration), and transmits  $NEXT_R$  symbols using Bitmap- $N_R$  (in  $NEXT_R$  duration) according to the result of initialization. The ATU-R transmits  $FEXT_C$  symbols using Bitmap- $F_C$  (in  $FEXT_C$  duration), and transmits  $NEXT_C$  symbols using Bitmap- $N_C$  (in  $NEXT_C$  duration) in the same manner.



The ATU-C shall have the capability to disable transmission during NEXT<sub>C/R</sub> (see Table 11-i/G.994.1). In this case, the ATU-C shall transmit only the pilot tone as NEXT<sub>R</sub> symbol, and ATU-R shall transmit silence as the NEXT<sub>C</sub> symbol (see C.5.5 and C.5.7).

### C.3.3.5 Loop timing at ATU-R (new)

The phase relation between received symbol and transmitted symbol of ATU-R at reference point U-R shall meet the phase tolerances as shown in Figure C.5.

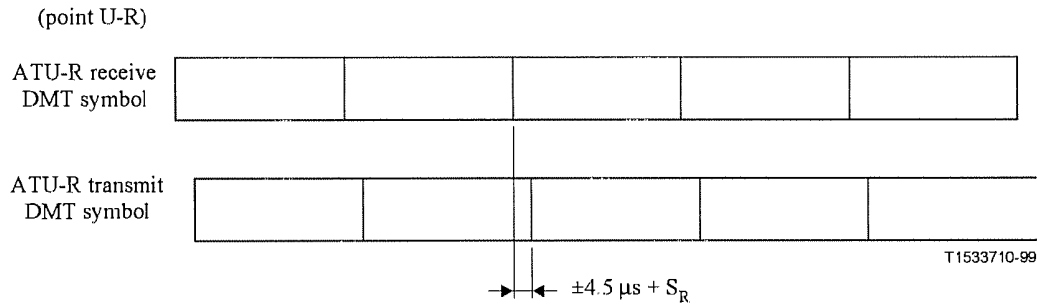
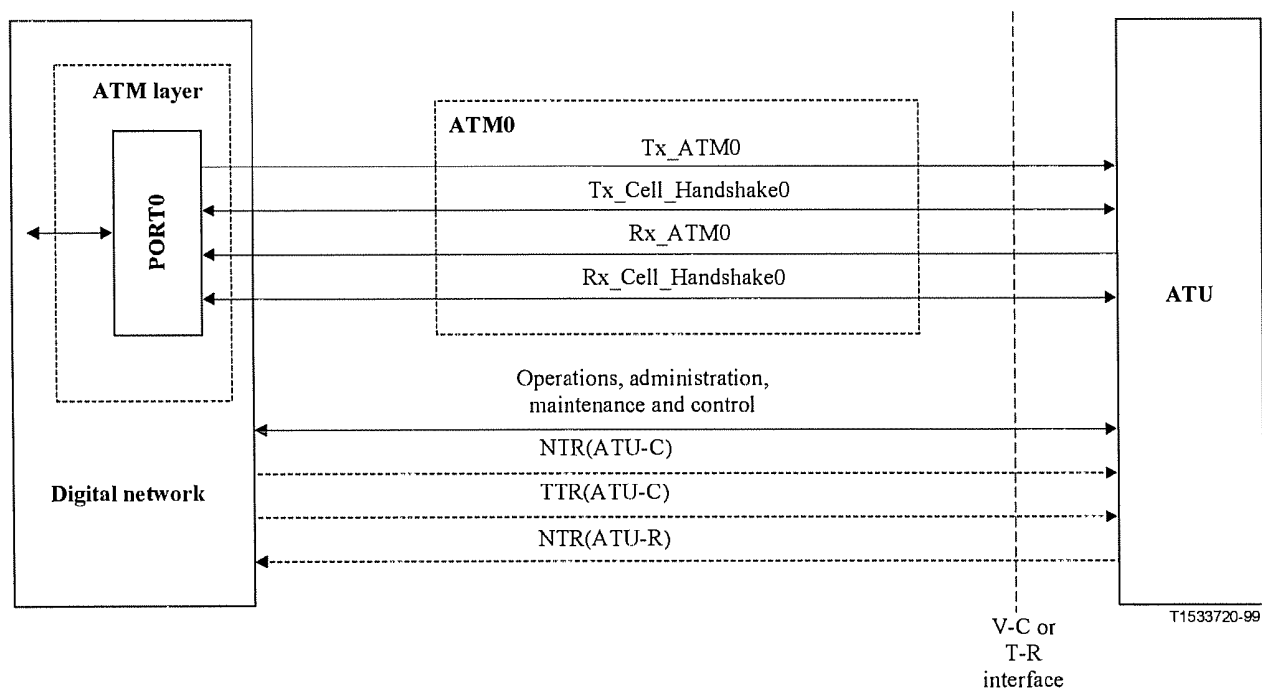


Figure C.5/G.992.2 -- Loop timing for ATU-R

## C.4 ATU interfaces

### C.4.1 ATM interface for ATM transport (replaces figure in 6.1)

The functional data interface at the ATU for ATM transport are shown in Figure C.6.



NOTE – The TTR may be generated in the ATU-C without being provided from the V-C reference point.

Figure C.6/G.992.2 – ATU functional interfaces to the ATM layer at the V or T reference point

**C.5 ATU functional characteristics (pertains to clause 7)****C.5.1 Payload transfer delay (supplements 7.1.1)**

The one-way transfer delay (excluding cell specific functionalities) for payload bits from the V reference point at the central office end (V-C) to the T reference point at remote the end (T-R) shall be as specified in 7.1.1 with an additional 5 ms for transfer delay attributed to the rate converter. The same requirement applies in the opposite direction, from the T-R reference point to the V-C reference point.

The maximum rate converter delay specified in the above text shall not apply to bit rates of 32 kbit/s and 64 kbit/s.

**C.5.2 Framing (pertains to 7.3)****C.5.2.1 Superframe structure (supplements 7.3.3.1)**

Since the rate converter reorders the user data and overhead bit-level data to create hyperframes, the input data frames to the constellation encoder are different than those defined in 7.3.3.1.

**C.5.2.2 Hyperframe structure (new)**

This annex uses the hyperframe structure shown in Figures C.7 and C.8. Both figures show the phase relationship between the  $TTR_{C/R}$  and the hyperframe at the point U-C and U-R. Each hyperframe is composed of five superframes, which are numbered from 0 to 4. In order to indicate the boundary of the hyperframe, the inverse synch symbol is used for the  $N_{inv}$ -th superframe, which is generated from a tone-by-tone 180-degree phase reversal of the synchronization symbol (see C.5.3.1) except for the pilot tone.  $N_{inv}$ -th is defined as:

$$N_{inv}\text{-th} = \begin{array}{l} 3 \text{ (SPF\#3) for downstream} \\ 0 \text{ (SPF\#0) for upstream} \end{array}$$

The FEC Output Frame from the interleaver is put into the rate-converter. The bit-level data stream from the rate-converter is extracted according to the size of Bitmap- $F_{R/C}$  and Bitmap- $N_{R/C}$  using the Sliding Window (see C.3.3.2 and C.3.3.4).

In order to make the bit rate to be a multiple of 32 kbit/s, the dummy bits are inserted at the end of hyperframe by the rate converter (see C.5.6). The hyperframe is composed of 345 DMT symbols, numbered from 0 to 344. Each symbol is assigned as a  $FEXT_{R/C}$  or  $NEXT_{R/C}$  symbol in a  $FEXT_{R/C}$  or  $NEXT_{R/C}$  duration (see C.3.3.1). The following numerical formula gives the information which duration  $N_{dmt}$ -th DMT symbol belongs to at ATU transmitter.

Downstream data (see Figure C.9):

For ( $N_{dmt} = 0, 1, \dots, 344$ )

$$S = 272 \times N_{dmt} \bmod 2760$$

if { ( $S + 271 < a$ ) or ( $S > a + b$ ) } then  $FEXT_R$  symbol

else then  $NEXT_R$  symbol

where  $a = 1243$ ,  $b = 1461$

Upstream data (see Figure C.10):

For ( $N_{\text{dmt}} = 0, 1, \dots, 344$ )

$$S = 272 \times N_{\text{dmt}} \bmod 2760$$

if { ( $S > a$ ) and ( $S + 271 < a + b$ ) } then FEXT<sub>C</sub> symbol

else then NEXT<sub>C</sub> symbol

where  $a = 1315$ ,  $b = 1293$

Thus, 128 DMT symbols are allocated in the FEXT<sub>R/C</sub> duration (FEXT<sub>C/R</sub> symbols), and 217 DMT symbols are allocated in the NEXT<sub>R/C</sub> duration (NEXT<sub>C/R</sub> symbols). The symbols are composed of:

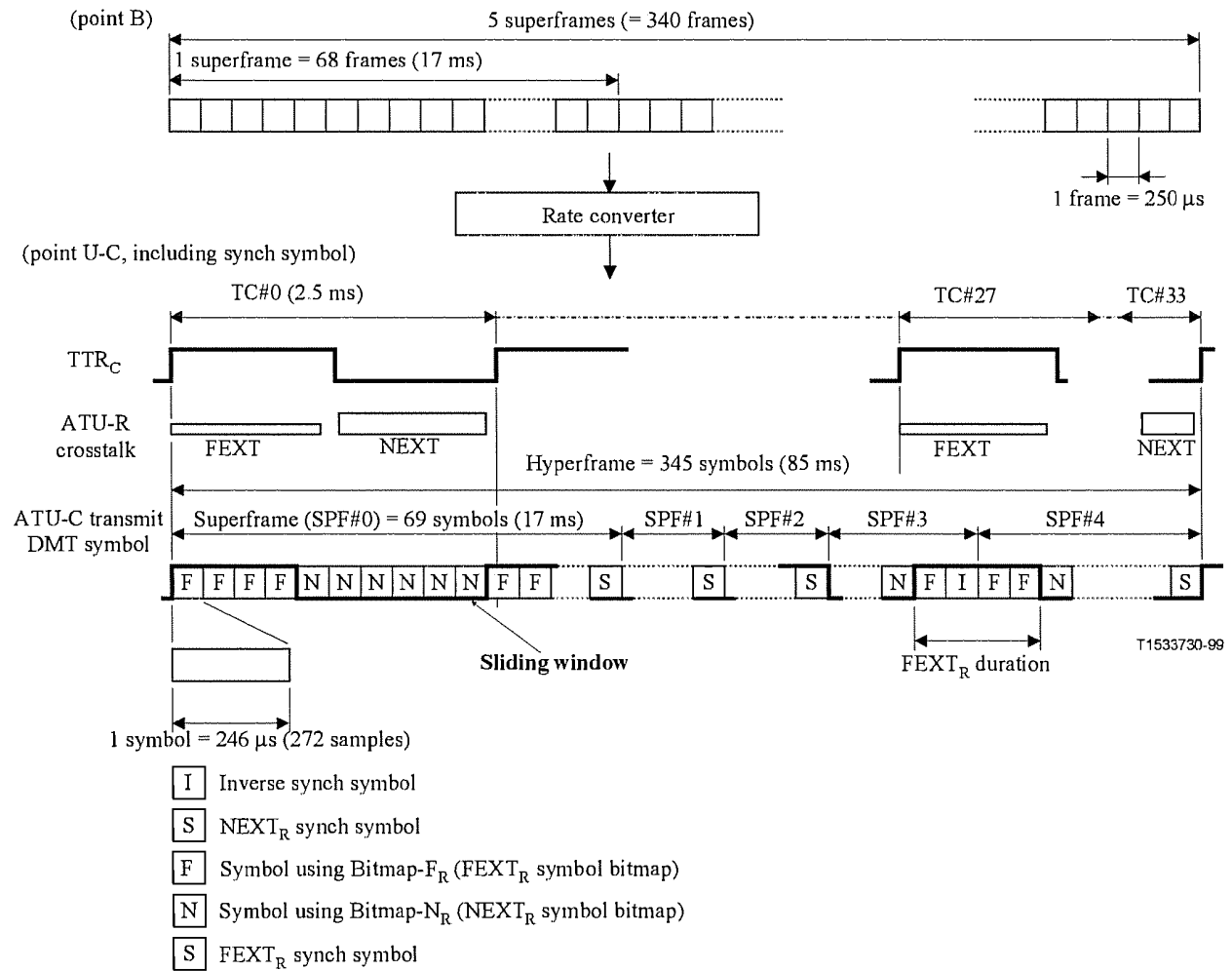
FEXT<sub>C/R</sub> symbol:

- Number of symbols using Bitmap-F<sub>R/C</sub> = 126
- Number of synch symbols = 1
- Number of inverse synch symbols = 1

NEXT<sub>C/R</sub> symbol:

- Number of symbols using Bitmap-N<sub>R/C</sub> = 214
- Number of synch symbols = 3

During FEXT Bitmap mode, the ATU-C shall transmit only the pilot tone as NEXT<sub>R</sub> symbol and the ATU-R shall not transmit any signal as NEXT<sub>C</sub> symbol.



**Figure C.7/G.992.2 – Hyperframe structure for downstream**

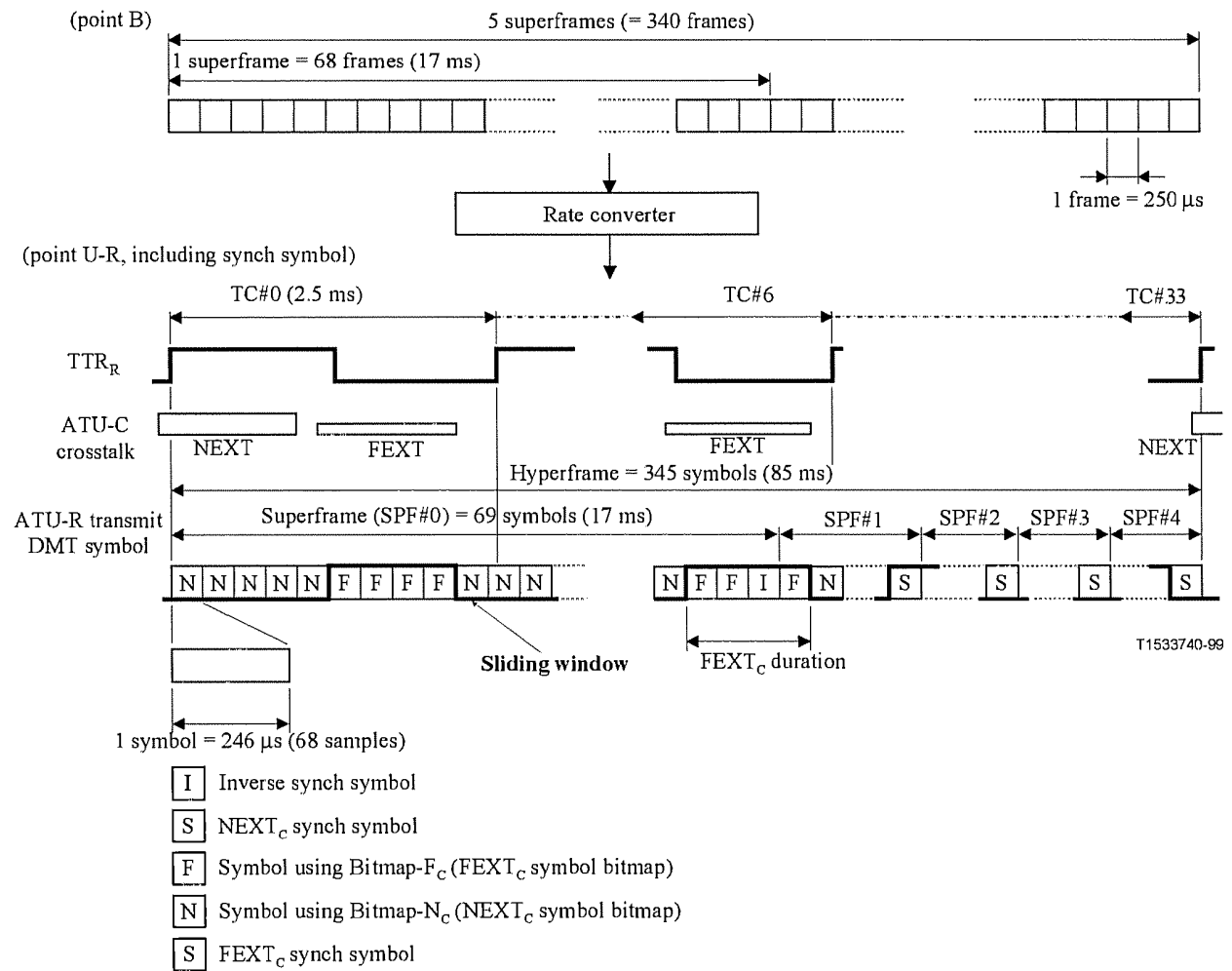


Figure C.8/G.992.2 – Hyperframe structure for upstream



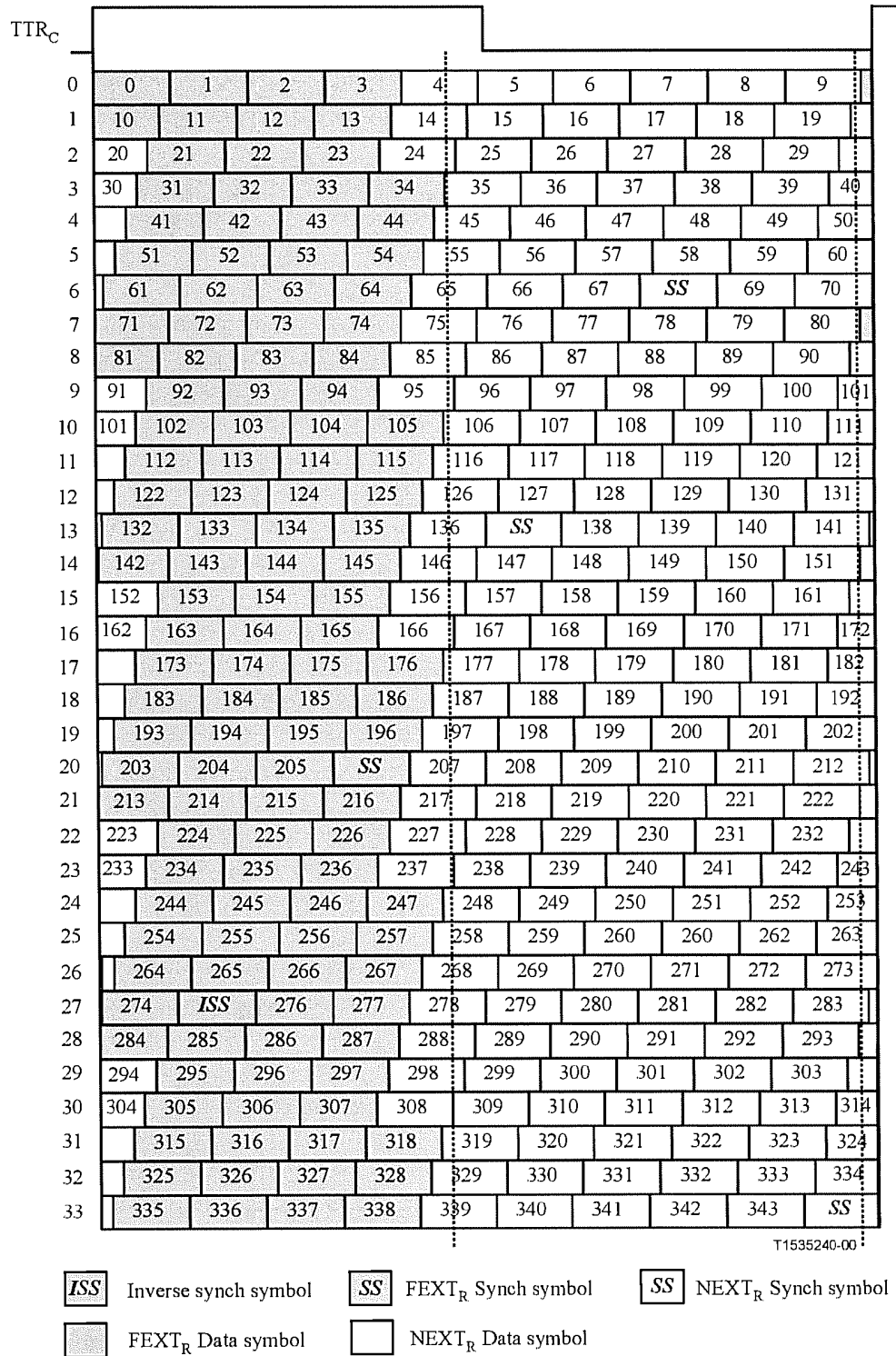
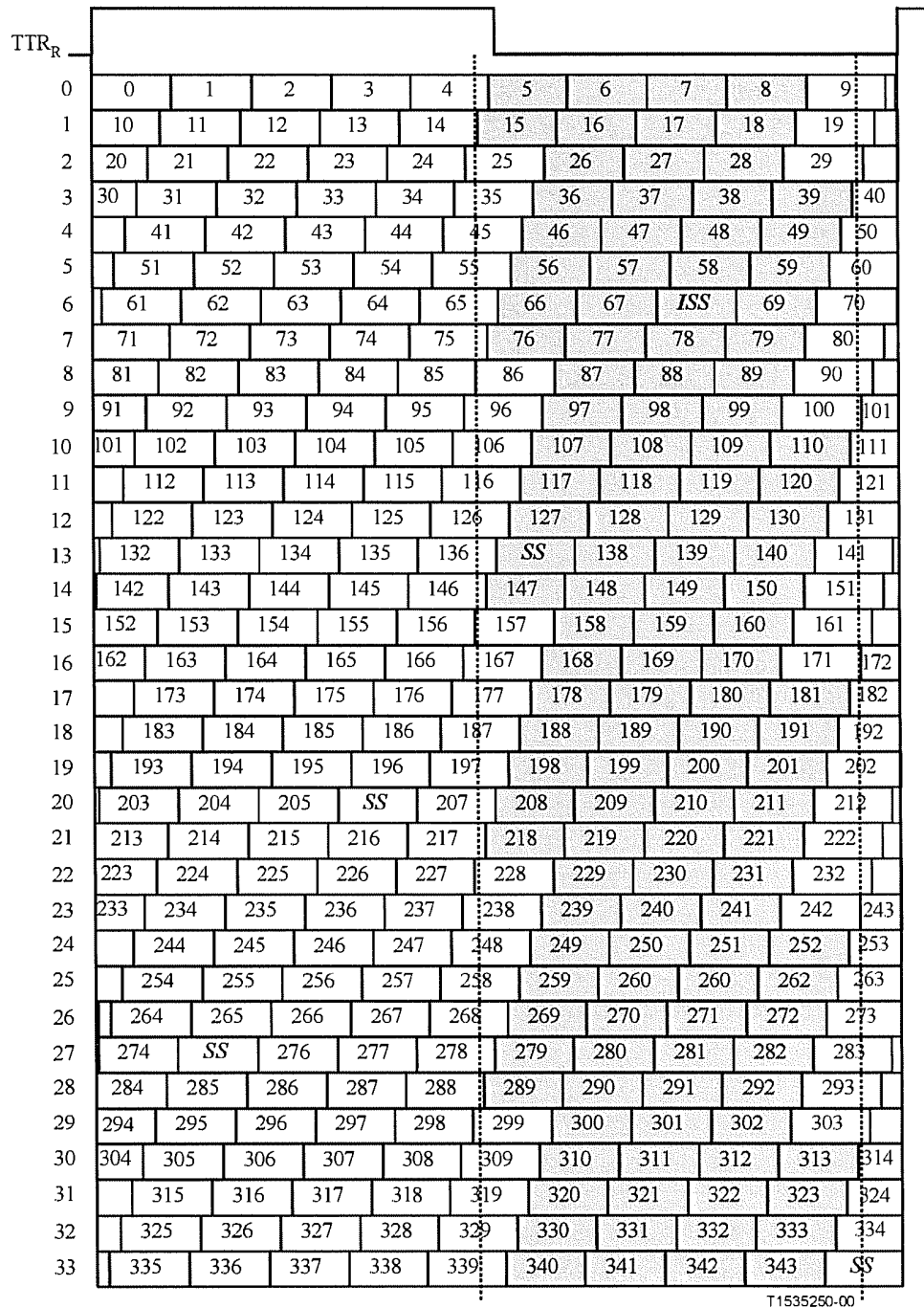


Figure C.9/G.992.2 – Symbol pattern in a hyperframe with cyclic prefix – Downstream



<b>ISS</b>	Inverse synch symbol	<b>SS</b>	FEXT <sub>C</sub> Synch symbol	<b>SS</b>	NEXT <sub>C</sub> Synch symbol
	FEXT <sub>C</sub> Data symbol		NEXT <sub>C</sub> Data symbol		

**Figure C.10/G.992.2 – Symbol pattern in a hyperframe with cyclic prefix – Upstream**

### C.5.3 Modulation (pertains to 7.10)

#### C.5.3.1 Inverse Synchronization Symbol (new)

Except for the pilot tone, the Inverse Synchronization symbol shall be generated from a tone-by-tone 180-degree phase reversal of Synchronization symbol (i.e. + maps to –, and – maps to +, for each of the 4-QAM signal constellation).

**C.5.3.2 Gain scaling of synchronization symbol**

At Initialization, the sync symbol reference transmit PSD level shall be set at the reference PSD level  $+ 10\log(g_{\text{sync}}^2)$  dBm/Hz, with  $g_{\text{sync}}^2$  defined as the average  $g_i^2$  value over the used (i.e.  $b_i > 0$ ) subcarriers in the NEXT or FEXT bitmap, whichever results in the highest average gain. The sync symbol reference transmit PSD shall not be updated with used subcarrier gain changes during SHOWTIME.

**C.5.4 Transmitter spectral mask (replaces 7.12.3)**

The spectral mask of this annex shall use the same masks as Annex A or Annex B. When C-MSG1 bit 16 is 0, the PSD mask specified in Annex A shall be used. When C-MSG1 bit 16 is 1, the PSD mask specified in Annex B shall be used.

**C.5.5 Dual Bitmap (new)**

The Dual Bitmap method has individual bit rates under the FEXT and NEXT noise, and this needs an additional bit and gain table,  $\{b_i, g_i\}$ . The dual bitmaps are switched synchronized with the sliding window pattern of NEXT/FEXT symbols.

**C.5.6 Rate Converter (new)**

The output of the interleaver is input to the rate converter. The rate converter buffering changes the data frame boundaries between the reference points B and C according to Bitmap- $F_{R/C}$ , Bitmap- $N_{R/C}$  and the Sliding Window. However for the difference of the data rates between the reference points B and C, and to make the bit rate to be a multiple of 32 kbit/s, the dummy bits are inserted at the end of the hyperframe. The number of the dummy bits shall be:

$$\# \text{dummy}_R = (f_R \times 126 + n_R \times 214) - (t_R \times 340) \quad \text{for downstream data}$$

$$\# \text{dummy}_C = (f_C \times 126 + n_C \times 214) - (t_C \times 340) \quad \text{for upstream data}$$

where  $t_R$  is the number of allocated bits in one frame at the reference point B in ATU-C transmitter,  $f_R$  and  $n_R$  are the numbers of bits in Bitmap- $F_R$  and Bitmap- $N_R$ , respectively. Similarly, where  $t_C$  is the number of allocated bits in one frame at the reference point B in ATU-R transmitter,  $f_C$  and  $n_C$  are the numbers of bits in Bitmap- $F_C$  and Bitmap- $N_C$ , respectively. During FEXT Bitmap mode,  $n_R$  and  $n_C$  are zero.

At the receiver, the inserted dummy bits shall be removed.

The receiver shall determine Bitmap- $F_{R/C}$  and Bitmap- $N_{R/C}$  so that the number of dummy bits is less than 126 in initialization sequence.

**C.5.7 FEXT Bitmap (new)**

The FEXT Bitmap mode uses the Dual Bitmap technique (see C.5.5) only during FEXT. When Bitmap- $N_R$  and Bitmap- $N_C$  are disabled (see Table 11-i/G.994.1), the ATU-C shall transmit only the pilot tone as NEXT $_R$  symbol and the ATU-R shall not transmit any signal as NEXT $_C$  symbol (see Figures C.7 and C.8).

The Dual versus FEXT bit mapping mode is selected during G.994.1 using bit "DBM" (see 11.2 and 11.3).

**C.6 aoc on-line adaptation and reconfiguration (pertains to clause 9)****C.6.1 Bit swap request message encoding (replaces 9.2.4)**

This message tells the transmitter which subcarriers are to be modified. The format of the request is shown in Table C.1.

**Table C.1/G.992.2 – Format of the bit swap request message**

Message header	Message field 1-4		
{11111111 <sub>b</sub> } (8 bits)	Bitmap index (1 bit)	Command (7 bits)	Subcarrier index (8 bits)

The request shall comprise nine bytes as follows:

- An aoc message header consisting of eight binary ones.
- Message fields 1-4, each of which each consists of a one-bit bitmap index, a seven-bit command followed by a related eight-bit subcarrier index. One-bit bitmap index and valid seven-bit commands for the bit swap message shall be as shown in Table C.2. In Table C.2, the MSB for the bit swap request command represents the bitmap index. In the Bitmap index, 0 indicates Bitmap F<sub>R</sub>, and 1<sub>b</sub> indicates N<sub>R</sub> for downstream data. Similarly, 0 indicates Bitmap F<sub>C</sub> and 1<sub>b</sub> indicates N<sub>C</sub> for upstream data. The eight-bit subcarrier index is counted from low to high frequencies with the lowest frequency subcarrier having the number zero. The subcarrier index zero shall not be used.
- The bit swap between FEXT<sub>C/R</sub> symbols and NEXT<sub>C/R</sub> symbols is not allowed.

**Table C.2/G.992.2 – Bit swap request command**

Value (8 bit)	Interpretation
y0000000 <sub>b</sub>	Do nothing
y0000001 <sub>b</sub>	Increase the number of allocated bits by one
y0000010 <sub>b</sub>	Decrease the number of allocated bits by one
y0000011 <sub>b</sub>	Increase the transmitted power by 1 dB
y0000100 <sub>b</sub>	Increase the transmitted power by 2 dB
y0000101 <sub>b</sub>	Increase the transmitted power by 3 dB
y0000110 <sub>b</sub>	Reduce the transmitted power by 1 dB
y0000111 <sub>b</sub>	Reduce the transmitted power by 2 dB
y0001xxx <sub>b</sub>	Reserved for vendor discretionary commands
NOTE – y is "0 <sub>b</sub> " for FEXT <sub>C/R</sub> symbols, and "1 <sub>b</sub> " for NEXT <sub>C/R</sub> symbols of the Sliding Window.	

To avoid  $g_i$  divergence between ATU-C and ATU-R after several bit swaps, for a  $g_i$  update of  $\Delta$  dB the new  $g_i$  value should be given by:

$$g_i' = (1/512) \times \text{round}(512 \times g_i \times 10^{\exp(\Delta/20)})$$

**C.6.2 Extended bit swap request message encoding (supplements 9.2.5)**

The format of the extended bit swap request is shown in Table C.3.

**Table C.3/G.992.2 – Format of the bit swap request message**

Message header	Message field 1-6		
{11111100 <sub>b</sub> } (8 bits)	Bitmap index (1 bit)	Command (7 bits)	Subcarrier index (8 bits)

In the same manner as the bit swap request, each of the message fields of the extended bit swap request consists of a one-bit bitmap index, a seven-bit command followed by a related eight-bit subcarrier index.

**C.6.3 Bit swap acknowledge message encoding (supplements 9.2.6)**

The bit swap superframe counter number shall only indicate the last superframe (SPF#4) of a hyperframe.

The new bit and/or transmit power table(s) shall then take effect starting from the first frame (frame 0) of SPF#0 of a hyperframe.

If the bit swap superframe counter number contained in the received bit swap acknowledge message does not indicate SPF#4, then the new table(s) shall take effect starting from frame 0 of SPF#0 of the next hyperframe.

**C.7 In-service performance monitoring and surveillance (pertains to clause 10)****C.7.1 ADSL line related primitives (pertains to 10.1)****C.7.1.1 ADSL line related near-end defects (supplements 10.1.3)**

Two near-end defects are defined:

- *Loss of signal (LOS)*: ADSL power shall be measured only in the FEXT<sub>C</sub> duration at ATU-C, or only in the FEXT<sub>R</sub> duration at ATU-R.
- *Severely Errored Frame (SEF)*: A SEF defect occurs when the content of two consecutively received ADSL synchronization symbols in the FEXT<sub>C</sub> duration at ATU-C, or in the FEXT<sub>R</sub> duration at ATU-R, does not correlate with the expected content over a subset of the tones. A SEF defect terminates when the content of two consecutively received ADSL synchronization symbols in the FEXT<sub>C</sub> duration at ATU-C, or in the FEXT<sub>R</sub> duration at ATU-R, correlate with the expected contents over the same subset. The correlation method, the selected subset of tones, and the threshold for declaring these defect conditions are implementation discretionary.

**C.7.1.2 ADSL line related far-end defects (supplements 10.1.4)**

*Far-end Loss of signal (LOS)*: The ADSL power shall be measured only in the FEXT<sub>C</sub> duration at ATU-C, or only in the FEXT<sub>R</sub> duration at ATU-R.



**C.7.2 Test parameters (supplements 10.4)****C.7.2.1 Near-end test parameters (supplements 10.4.1)**

The following near-end test parameters are defined:

- *Attenuation (ATN)*: The received signal power shall be measured only in the FEXT<sub>C</sub> duration at ATU-C, or only in the FEXT<sub>R</sub> duration at ATU-R.
- *Signal-to-Noise ratio (SNR) margin*: During the FEXT Bitmap mode, this primitive represents the SNR margin in the FEXT<sub>C</sub> duration at ATU-C, or in the FEXT<sub>R</sub> duration at ATU-R.

**C.7.2.2 Far-end test parameters (supplements 10.4.2)**

The following far-end test parameters are defined:

- *Attenuation (ATN)*: The received signal power shall be measured only in the FEXT<sub>C</sub> duration at ATU-C, or only in the FEXT<sub>R</sub> duration at ATU-R.
- *Signal-to-Noise ratio (SNR) margin*: During the FEXT Bitmap mode, this primitive represents the SNR margin in the FEXT<sub>C</sub> duration at ATU-C, or in the FEXT<sub>R</sub> duration at ATU-R.

**C.8 Initialization****C.8.1 Initialization with Hyperframe (new)**

The exchange of messages between ATU-C and ATU-R are performed using FEXT<sub>C</sub> and FEXT<sub>R</sub> symbols. The initialization sequence has two symbol rates. One is 4.3125 kbaud for the symbol without a cyclic prefix, and the other is  $4 \times 69/68$  kbaud for the symbol with a cyclic prefix. 32 TTR cycles have the same period as 345 times 4.3125 kHz DMT symbols, and 34 TTR cycles have the same period as 345 times  $4 \times 69/68$  kHz DMT symbols.

During FEXT Bitmap mode, the ATU-R shall not transmit any signal as the NEXT<sub>C</sub> symbols and the ATU-C shall transmit the pilot tone as the NEXT<sub>R</sub> symbols except:

- C-PILOT1 (C-PILOT1A): accompanied by A<sub>48</sub> signal (see C.8.3.1);
- C-QUIETn: not transmit any signal.

The ATU-C shall enter C-PILOT1 at the beginning of the hyperframe. The ATU-C transmits information regarding the phase of the TTR<sub>C</sub> to ATU-R during C-PILOT1. The ATU-R shall enter R-REVERB1 at the beginning of the hyperframe without cyclic prefix.

From C-PILOT1 to C-SEGUE1, the following numerical formula gives the information which duration N<sub>dmt</sub>-th DMT symbol belongs to (see Figure C.11):

For (N<sub>dmt</sub> = 0, 1, ..., 344)

$$S = 256 \times N_{dmt} \bmod 2760$$

if { (S + 255 < a) or (S > a + b) }      then FEXT<sub>R</sub> symbol  
     else      then NEXT<sub>R</sub> symbol

where a = 1243, b = 1461

In order to enter C-RATES1 at the beginning of the hyperframe with cyclic prefix, the number of symbols from C-PILOT1 to C-SEGUE1 shall be a multiple of 345 DMT symbols.

From R-REVERB1 to R-SEGUE1, the following numerical formula gives the information which duration  $N_{\text{dmt}}$ -th DMT symbol belongs to (see Figure C.12):

For  $S = 256 \times N_{\text{dmt}} \bmod 2760$  ( $N_{\text{dmt}} = 0, 1, \dots, 344$ )

if { $(S > a)$ and $(S + 255 < a + b)$ }	then FEXT <sub>C</sub> symbol
else	then NEXT <sub>C</sub> symbol

where  $a = 1315$ ,  $b = 1293$

From C-RATES1 to C-SEGUE3, the number of symbols is a multiple of 345 DMT symbols. The following numerical formula gives the information which duration  $N_{\text{dmt}}$ -th DMT symbol belongs to. ATU-C transmits the message data in FEXT<sub>R</sub> symbols (see Figure C.9).

For ( $N_{\text{dmt}} = 0, 1, \dots, 344$ )

$S = 272 \times N_{\text{dmt}} \bmod 2760$

if { $(S + 271 < a)$ or $(S > a + b)$ }	then FEXT <sub>R</sub> symbol
else	then NEXT <sub>R</sub> symbol

where  $a = 1243$ ,  $b = 1461$

The ATU-R enters R-REVERB3 at the beginning of the hyperframe with cyclic prefix, which is extracted from received signal. From R-REVERB3 to R-SEGUE5 the number of symbols is a multiple of 345 DMT symbols. The following numerical formula gives the information which duration  $N_{\text{dmt}}$ -th DMT symbol belongs to. ATU-R transmits the message data in FEXT<sub>C</sub> symbols (see Figure C.10).

For ( $N_{\text{dmt}} = 0, 1, \dots, 344$ )

$S = 272 \times N_{\text{dmt}} \bmod 2760$

if { $(S > a)$ and $(S + 271 < a + b)$ }	then FEXT <sub>C</sub> symbol
else	then NEXT <sub>C</sub> symbol

where  $a = 1315$ ,  $b = 1293$

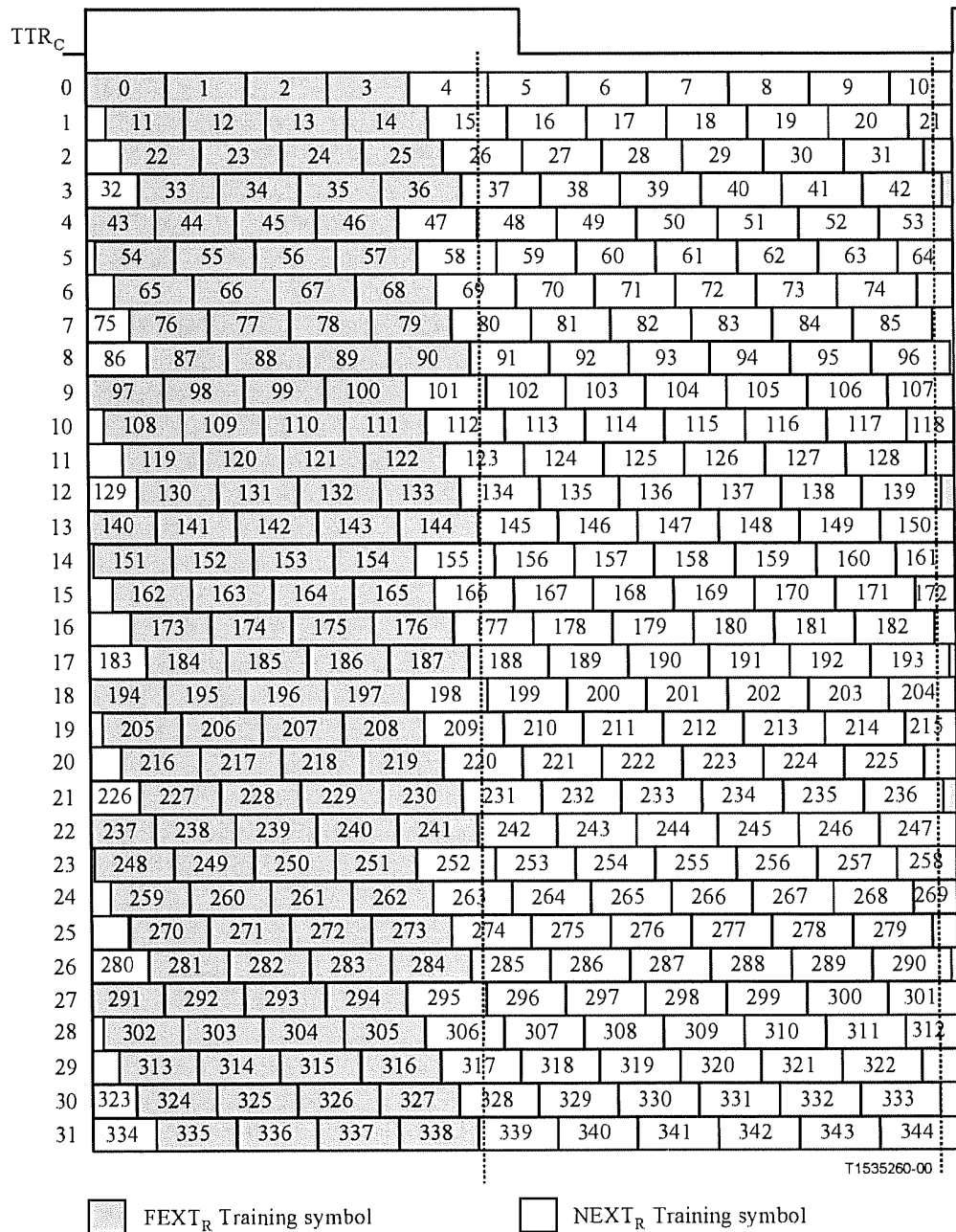
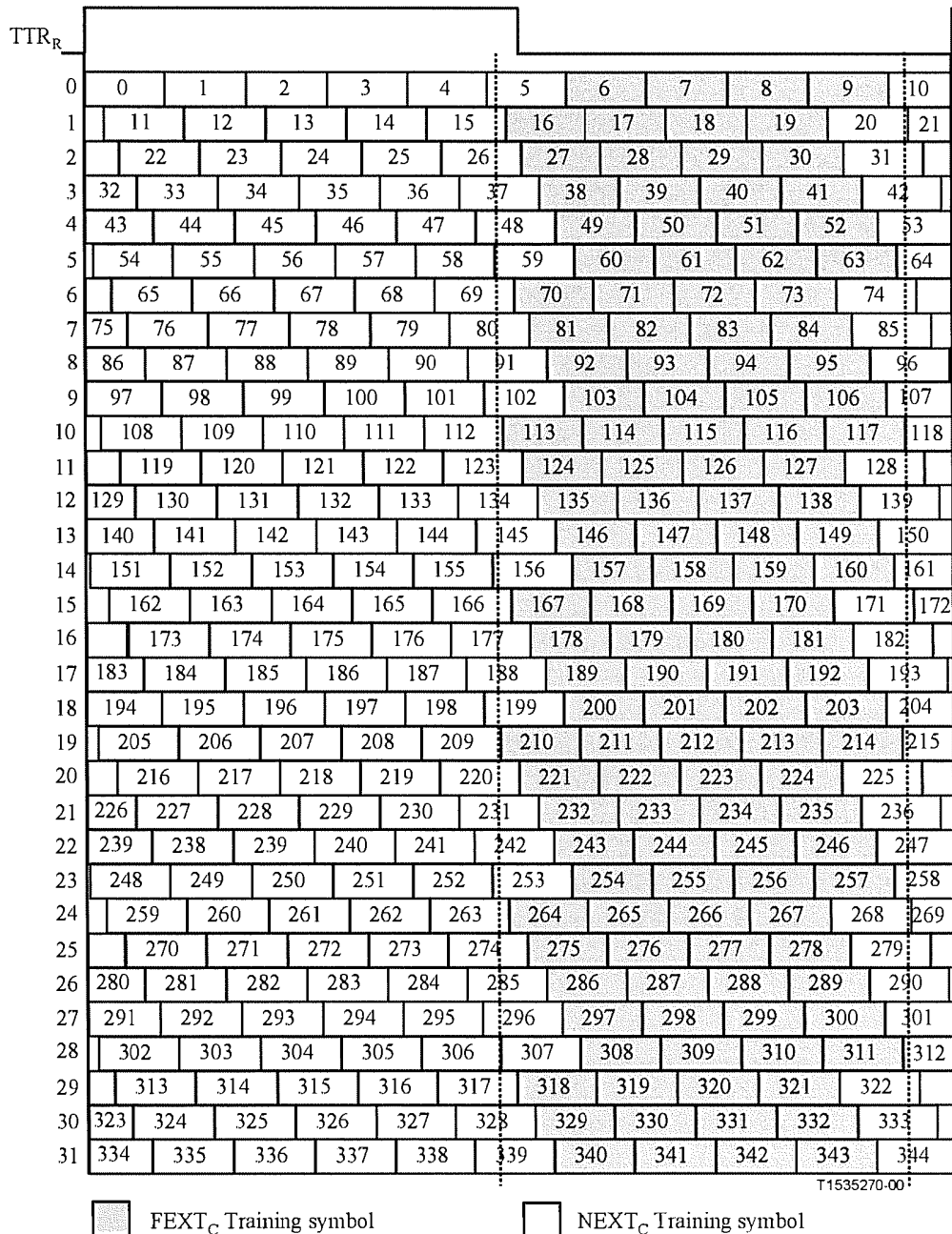


Figure C.11/G.992.2 – Symbol pattern in a hyperframe without cyclic prefix – Downstream



**Figure C.12/G.992.2 – Symbol pattern in a hyperframe without cyclic prefix – Upstream**

## **C.8.2 Escape from Handshake to Fast Retrain (replaces 11.5)**

See Figure C.13.

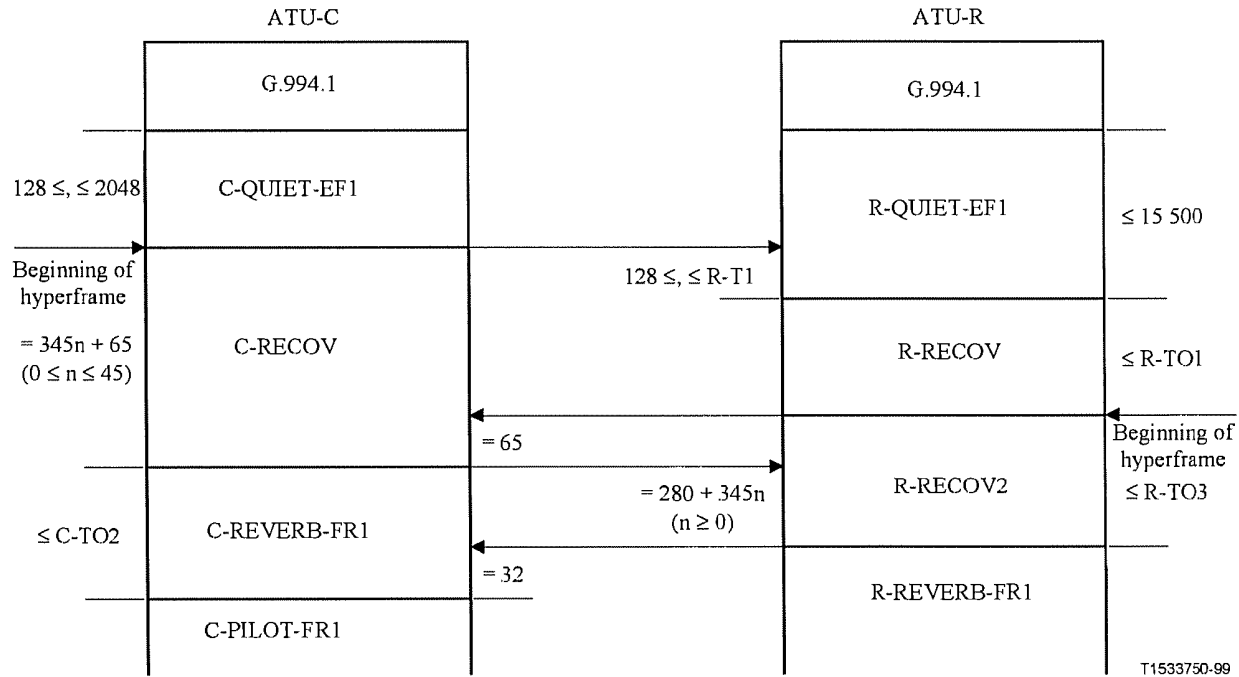
### **C.8.2.1 C-QUIET-EF1 (replaces 11.5.1)**

C-QUIET-EF1 begins at the termination of G.994.1. The minimum duration of C-QUIET-EF1 is 128 symbols. The maximum duration of C-QUIET-EF1 is 2048 symbols. The ATU-C terminates C-QUIET-EF1 and enters C-RECOV at the beginning of the hyperframe.

**C.8.2.2 R-QUIET-EF1 (replaces 11.5.2)**

R-QUIET-EF1 begins at the termination of G.994.1. The minimum duration of R-QUIET-EF1 is 128 DMT symbols after the detection of C-RECOV. The ATU-R shall progress to R-RECOV only after it has detected any part of the C-RECOV signal that is needed for reliable detection. The ATU-R enters R-RECOV2 synchronized with the hyperframe after the synchronization of ADC clock with the received C-RECOV signal.

Time-outs C-TO2, R-TO1, R-TO3 are vendor discretionary. It is advisable to make these duration as short as possible.



**Figure C.13/G.992.2 – Timing diagram of Escape to Fast Retrain**

**C.8.3 Transceiver training – ATU-C (supplements 11.7)**

During transceiver training from C-REVERB1 to C-SEGUE1 except C-PILOT<sub>n</sub> and C-QUIET<sub>n</sub>, the ATU-C shall transmit both FEXT<sub>R</sub> and NEXT<sub>R</sub> symbols when Bitmap-N<sub>R</sub> is enabled (Dual Bitmap mode), and shall not transmit NEXT<sub>R</sub> symbols except the pilot tone when Bitmap-N<sub>R</sub> is disabled (FEXT Bitmap mode). The duration of each state is defined in Figure C.18.

**C.8.3.1 C-PILOT1 (supplements 11.7.2)**

The ATU-C shall start its N<sub>SWF</sub> counter immediately after entering C-PILOT1, and then increment the N<sub>SWF</sub> counter with modulo 345 from 0 when it transmits each DMT symbol. According to the sliding window function and this counter, the ATU-C decides to transmit all of the subsequent symbols in either FEXT<sub>R</sub> or NEXT<sub>R</sub> symbols (see Figures C.11 and C.9).

C-PILOT1 has two subcarriers. One is the pilot tone as a single frequency sinusoid at 276 kHz (see 11.7.2).



A second carrier ( $A_{48}$ : 48-th carrier) is used to transmit  $NEXT_R$ / $FEXT_R$  information. The ATU-R can detect the phase information of the  $TTR_C$  from the  $A_{48}$  signal. The constellation encoding of the 48-th carrier with 2-bit constellation shall be as the follows:

(+ , +); indicates a  $FEXT_R$  symbol

(+ , -); indicates a  $NEXT_R$  symbol

### C.8.3.2 C-PILOT1A (supplements 11.7.3)

C-PILOT1A has two subcarriers and it is the same transmitted signal as C-PILOT1 (see C.8.3.1).

### C.8.3.3 C-REVERB3 (supplements 11.7.11)

In order to synchronize the first symbol of C-RATES1 with the beginning of the hyperframe and to inform the entering timing of C-RATES1 to ATU-R, the first symbol of C-SEGUE1 shall be transmitted inside of the  $FEXT_R$  duration. Therefore, the duration of C-REVERB3 is 3628 DMT symbols (see Figure C.14).

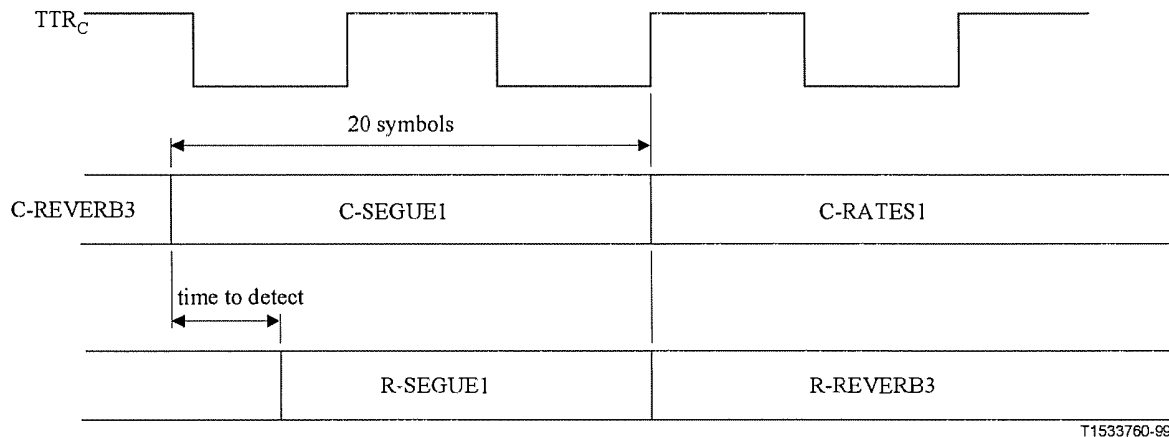


Figure C.14/G.992.2 – Timing diagram of C-SEGUE1 to C-RATES1

## C.8.4 Transceiver training – ATU-R (supplements 11.8)

During transceiver training from R-REVERB1 to R-SEGUE1 except R-QUIET<sub>n</sub>, the ATU-R shall transmit both  $FEXT_C$  and  $NEXT_C$  symbols when Bitmap- $N_C$  is enabled (Dual Bitmap mode) and shall not transmit  $NEXT_C$  symbols when Bitmap- $N_C$  is disabled ( $FEXT$  Bitmap mode). The duration of each state is defined in Figure C.18.

### C.8.4.1 R-QUIET2 (supplements 11.8.1)

The ATU-R enters R-REVERB1 after it completes timing recovery and Hyperframe synchronization from C-PILOT1/C-PILOT1A.

### C.8.4.2 R-REVERB1 (supplements 11.8.2)

The ATU-R shall start its  $N_{SWF}$  counter immediately after entering R-REVERB1, and then increment the  $N_{SWF}$  counter modulo 345 from 0 when it transmits each DMT symbol. The ATU-C and ATU-R shall have the same value since hyperframe alignment between the ATU-C and ATU-R shall be maintained. According to the sliding window and this counter, the ATU-R decides to transmit all of the subsequent symbols in either the  $FEXT_C$  or the  $NEXT_C$  symbol.

**C.8.4.3 R-QUIET3 (replaces 11.8.3)**

The final symbol of R-QUIET3 accommodates the frame alignment of the transmitter to that of the receiver. It may be shortened by any number of samples. The maximum duration of R-QUIET3 is 6145 DMT symbols.

**C.8.4.4 R-REVERB2 (supplements 11.8.5)**

After ATU-R detects C-SEGUE1, the ATU-R enters R-SEGUE1. The maximum duration of R-REVERB2 is 3643 DMT symbols.

**C.8.5 Channel analysis (ATU-C) (supplements 11.9)**

The ATU-C shall transmit the  $FEXT_R$  symbols, and shall not transmit the  $NEXT_R$  symbols except the pilot tone from C-RATES1 to C-CRC2. In C-MEDLEY, ATU-C shall transmit both  $FEXT_R$  and  $NEXT_R$  symbols, when Bitmap- $N_R$  is enabled (Dual Bitmap mode). ATU-C shall not transmit  $NEXT_R$  symbols except pilot tone, when Bitmap- $N_R$  is disabled (FEXT Bitmap mode). The duration of each state is defined in Figure C.18.

**C.8.5.1 C-SEGUE1 (supplements 11.9.1)**

The duration of C-SEGUE1 is 20 symbols in order that the first symbol of C-SEGUE1 shall be inside of the  $FEXT_R$  duration (see Figure C.14).

**C.8.5.2 C-MEDLEY (supplements 11.9.6)**

The definition of C-MEDLEY is the same as in 11.9.6, except for the duration of the SNR estimation at ATU-R for the downstream. With the periodical noise of TCM- ISDN, the SNR also changes in the same cycle, as shown in Figure C.15. ATU-C transmits the signal in both of  $FEXT_R$  and  $NEXT_R$  symbols and ATU-R estimates two SNRs from the received  $NEXT_R$  and  $FEXT_R$  symbols, respectively, as defined in Figure C.16.

The following numerical formula gives the information that received  $N_{dmt}$ -th DMT symbol at ATU-R belongs to:

For ( $N_{dmt} = 0, 1, \dots, 344$ )

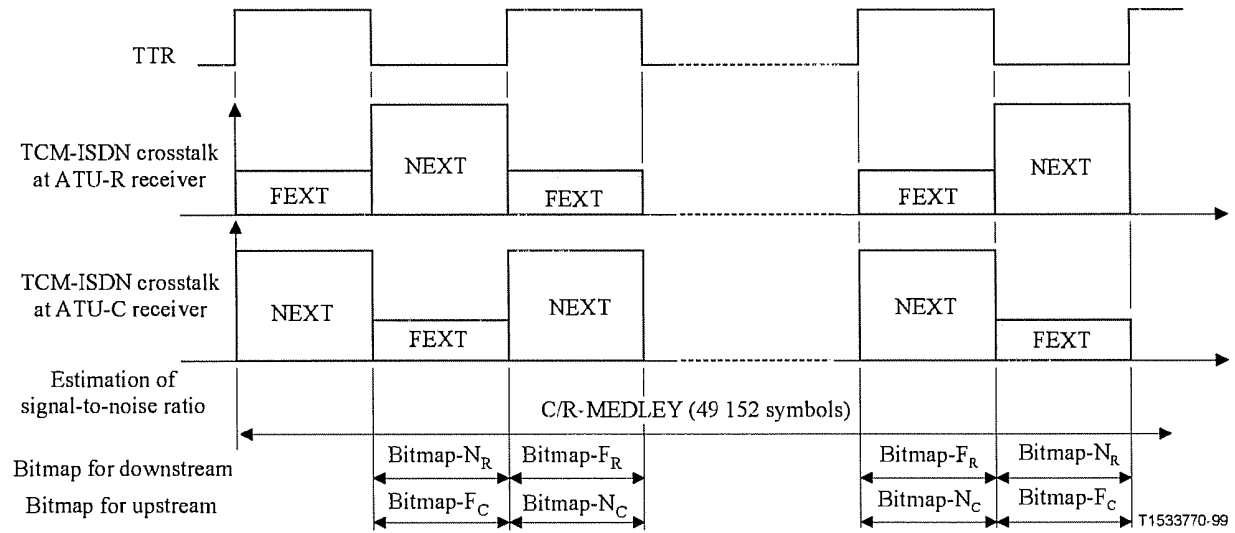
$$S = 272 \times N_{dmt} \bmod 2760$$

if { ( $S + 271 < a$ ) or ( $S > d$ ) } then symbol for estimation of  $FEXT_R$  SNR

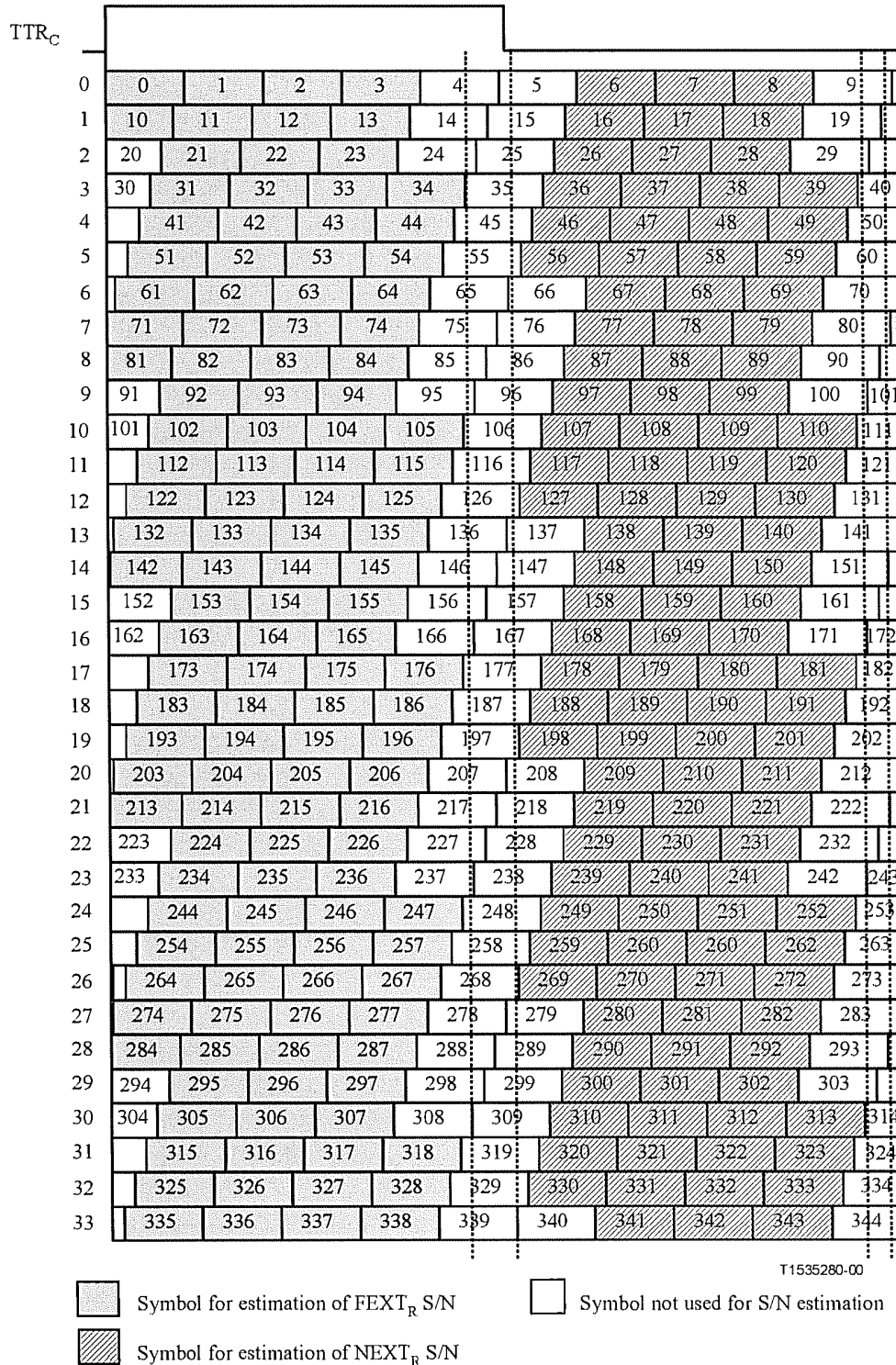
if { ( $S > b$ ) and ( $S + 271 < c$ ) } then symbol for estimation of  $NEXT_R$  SNR

where  $a = 1243$ ,  $b = 1403$ ,  $c = 2613$ ,  $d = 2704$

When Bitmap- $N_R$  is disabled (FEXT Bitmap mode), ATU-C shall transmit only the pilot tone as  $NEXT_R$  symbol.



**Figure C.15/G.992.2 – Estimation of periodic Signal-to-Noise Ratio**



**Figure C.16/G.992.2 – Symbol pattern in a hyperframe for S/N estimation – Downstream**

### C.8.6 Channel analysis (ATU-R) (supplements 11.10)

From R-RATES1 to R-CRC2, the ATU-R shall transmit the FEXT<sub>C</sub> symbols and shall not transmit the NEXT<sub>C</sub> symbols. In R-SEGUE2 and R-MEDLEY, the ATU-R shall transmit both FEXT<sub>C</sub> and NEXT<sub>C</sub> symbols when Bitmap-N<sub>C</sub> is enabled (Dual Bitmap mode) and shall not transmit NEXT<sub>C</sub>

symbols when Bitmap- $N_C$  is disabled (FEXT Bitmap mode). The duration of each state is defined in Figure C.18.

#### **C.8.6.1 R-SEGUE1 (supplements 11.10.1)**

The maximum duration of R-SEGUE1 is 14 symbols (see Figure C.14).

#### **C.8.6.2 R-REVERB3 (supplements 11.10.2)**

The ATU-R shall start R-REVERB3 aligned with the beginning of a Hyperframe.

#### **C.8.6.3 R-SEGUE2 (supplements 11.10.3)**

The duration of R-SEGUE2 is 13 symbols.

#### **C.8.6.4 R-MEDLEY (supplements 11.10.8)**

The definition of R-MEDLEY is the same as in 11.10.8, except for the duration of the SNR estimation at the ATU-C for the upstream channel. With the periodic noise of TCM- ISDN, the SNR also changes in the same cycle, as shown in Figure C.15. The ATU-R shall transmit the signal in both of FEXT $_C$  and NEXT $_C$  symbols, and ATU-C shall estimate two SNRs from the received NEXT $_C$  and FEXT $_C$  symbols, respectively, as defined in Figure C.17.

The following numerical formula gives the information that received  $N_{\text{dmt}}$ -th DMT symbol at ATU-C belongs to:

For  $N_{\text{dmt}} = 0, 1, \dots, 344$

$$S = 272 \times N_{\text{dmt}} \bmod 2760$$

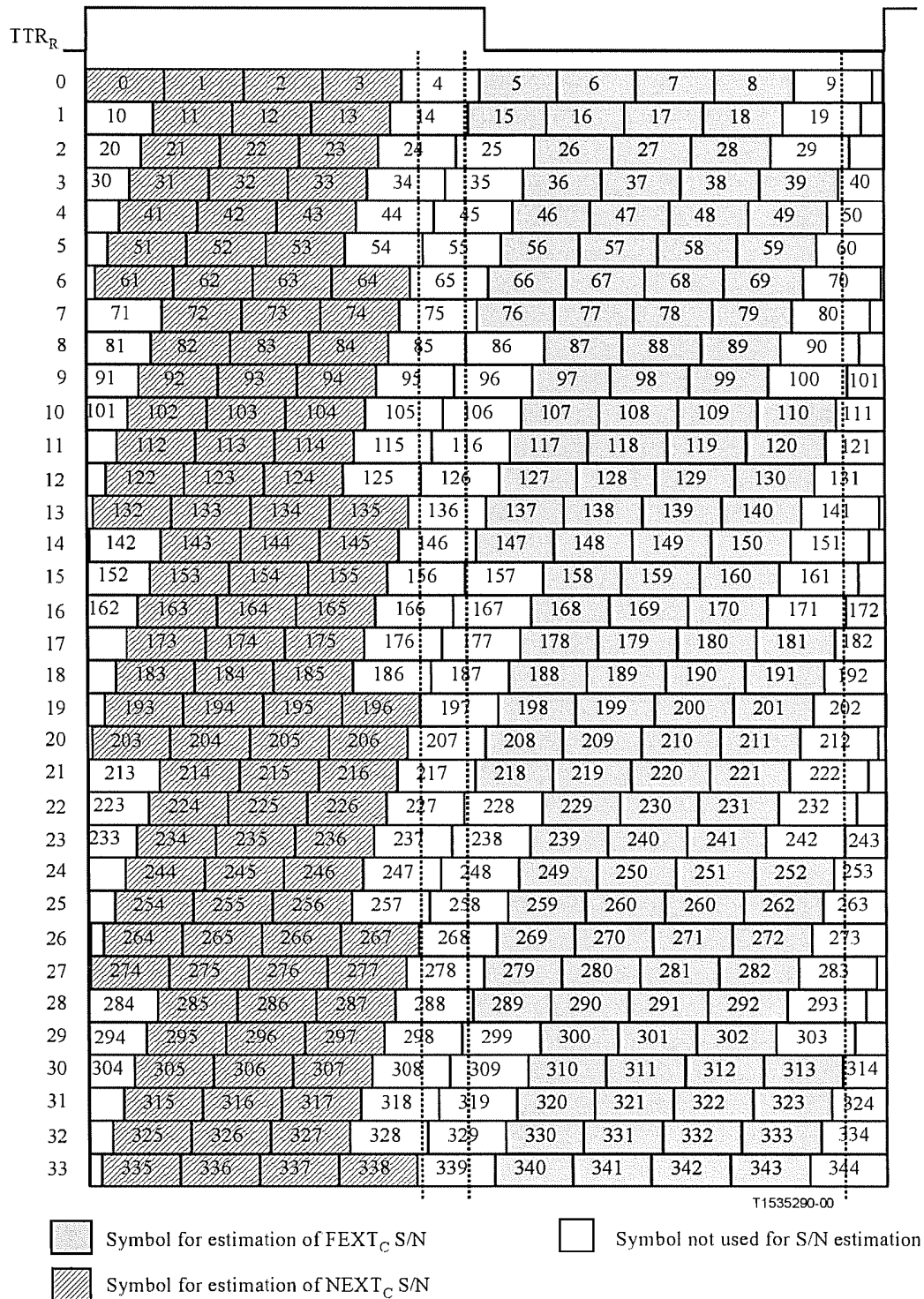
if {  $(S > b)$  and  $(S + 271 < c)$  } then symbol for estimation of FEXT $_C$  SNR

if {  $(S + 271 < a)$  } then symbol for estimation of NEXT $_C$  SNR

where  $a = 1148$ ,  $b = 1315$ ,  $c = 2608$

When Bitmap- $N_C$  is disabled (FEXT Bitmap mode), ATU-R shall not transmit NEXT $_C$  symbol.





**Figure C.17/G.992.2 – Symbol pattern in a hyperframe for S/N estimation – Upstream**

### C.8.7 Exchange – ATU-C (supplements 11.11)

During C-RATES<sub>n</sub>, C-MSG<sub>n</sub>, C-B&G, and C-CRC<sub>n</sub>, the ATU-C shall transmit the  $FEXT_R$  symbol. In the other signals, the ATU-C shall transmit both  $FEXT_R$  and  $NEXT_R$  symbols when Bitmap- $N_R$  is enabled (Dual Bitmap mode), and shall not transmit the  $NEXT_R$  symbols except pilot tone when Bitmap- $N_R$  is disabled (FEXT Bitmap mode). The duration of each state is defined in Figure C.19.

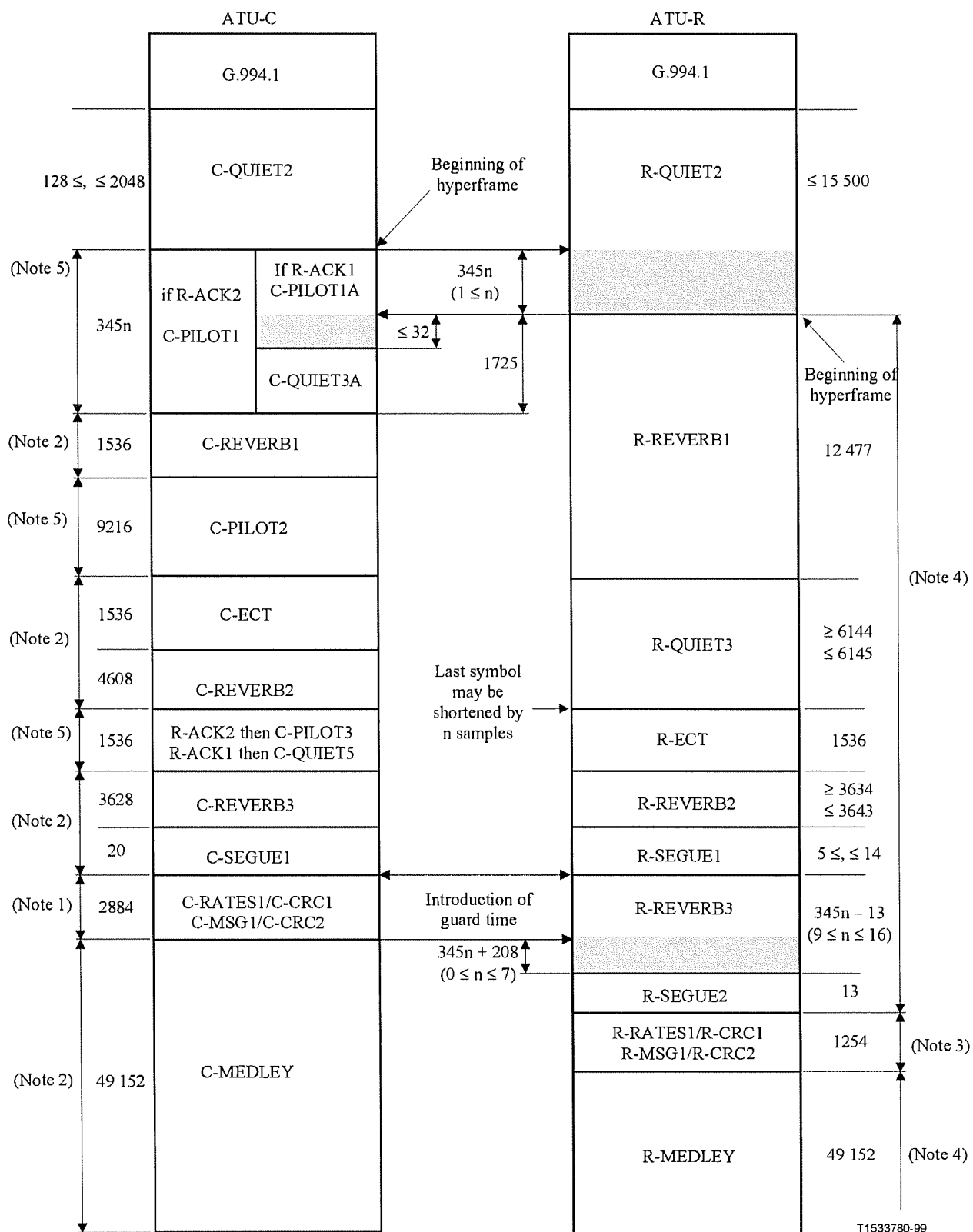


Figure C.18/G.992.2 – Timing diagram of the initialization sequence (part 1)

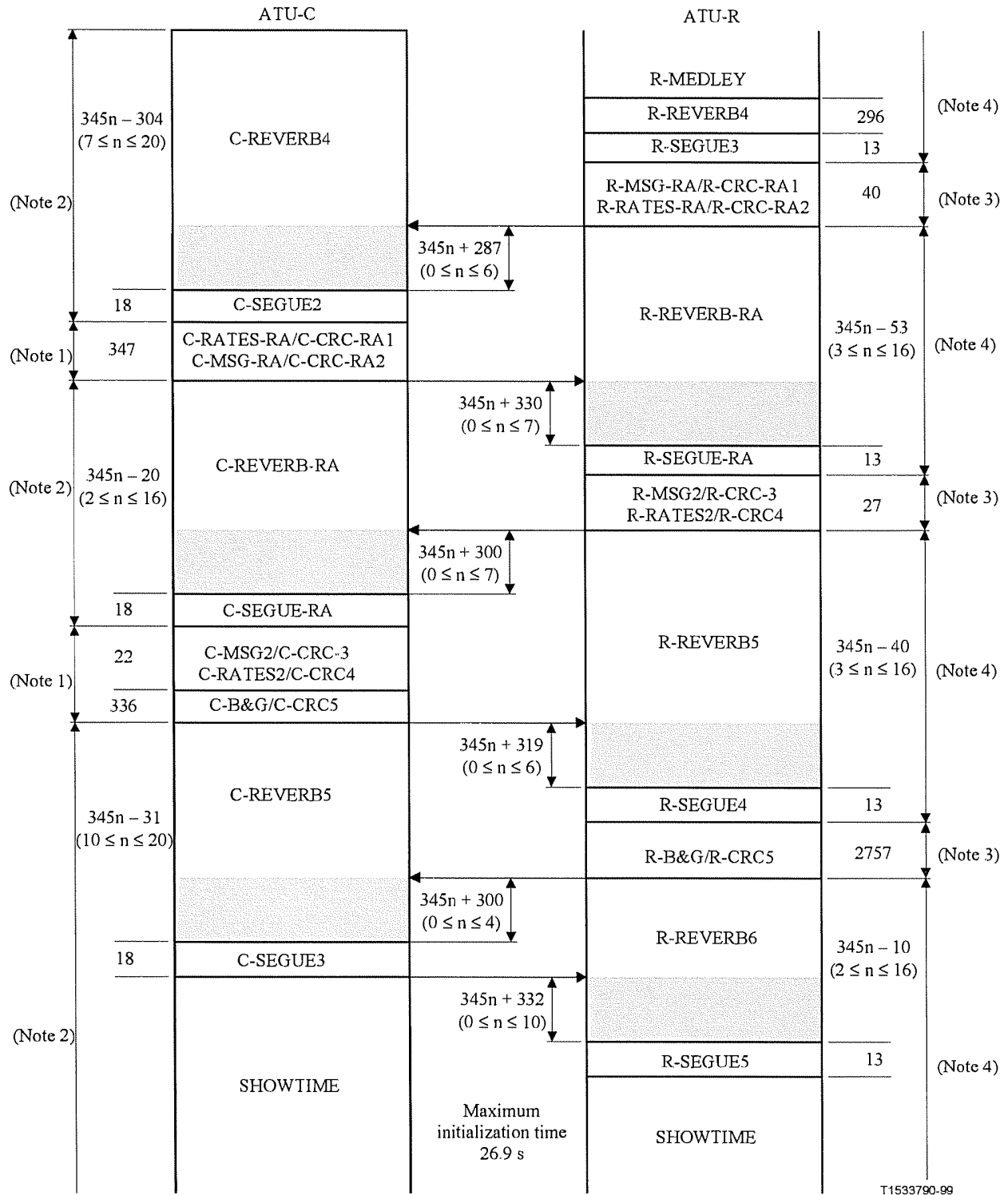


Figure C.19/G.992.2 – Timing diagram of the initialization sequence (part 2)

**Notes to Figures C.18 and C.19**

NOTE 1 – The ATU-C shall transmit the FEXT<sub>R</sub> symbols, and shall not transmit the NEXT<sub>R</sub> symbols except pilot tone.

NOTE 2 – The ATU-C shall transmit both FEXT<sub>R</sub> and NEXT<sub>R</sub> symbols, when Bitmap-N<sub>R</sub> is enabled (Dual Bitmap mode). ATU-C shall not transmit the NEXT<sub>R</sub> symbols except pilot tone, when Bitmap-N<sub>R</sub> is disabled (FEXT Bitmap mode).

NOTE 3 – ATU-R shall transmit the FEXT<sub>C</sub> symbols, and shall not transmit the NEXT<sub>C</sub> symbols.

NOTE 4 – ATU-R shall transmit both FEXT<sub>C</sub> and NEXT<sub>C</sub> symbols, when Bitmap-N<sub>C</sub> is enabled (Dual Bitmap mode). ATU-R shall not transmit NEXT<sub>C</sub> symbols, when Bitmap-N<sub>C</sub> is disabled (FEXT Bitmap mode).

NOTE 5 – ATU-C shall transmit both FEXT<sub>R</sub> and NEXT<sub>R</sub> symbols.

### **C.8.7.1 C-MSG2 (supplements to 11.11.9)**

#### **C.8.7.1.1 Total number of bits per symbol supported (supplements 11.11.9.4)**

The maximum number of bits per symbol is defined at the reference point B, that is calculated from the FEXT<sub>C</sub> and NEXT<sub>C</sub> upstream channel performance. (E.g. if the maximum numbers of bits that can be supported in FEXT<sub>C</sub> and NEXT<sub>C</sub> symbols are 111 and 88, {Total number of bits per symbol supported} =  $(111 \times 126 + 88 \times 214)/340 = 96$ ).

The number of symbols per hyperframe is 340. The number of FEXT symbols per hyperframe is 126. The number of NEXT symbols per hyperframe is 214.

#### **C.8.7.2 C-B&G (replaces 11.11.13)**

C-B&G shall be used to transmit to the ATU-R the bits and gains information, Bitmap-F<sub>C</sub>  $\{b_1, g_1, b_2, g_2, \dots, b_{31}, g_{31}\}$ , and Bitmap-N<sub>C</sub>  $\{b_{33}, g_{33}, b_{34}, g_{34}, \dots, b_{63}, g_{63}\}$ , that are to be used on the upstream carriers.  $b_i$  of Bitmap-F<sub>C</sub> indicates the number of bits to be coded by ATU-R transmitter onto the  $i$ -th upstream carrier in FEXT<sub>C</sub> symbols;  $g_i$  of Bitmap-F<sub>C</sub> indicates the scale factor, relative to the gain that was used for that carrier during the transmission of R-MEDLEY, that shall be applied to the  $i$ -th upstream carrier in FEXT<sub>C</sub> symbols. Similarly,  $b_i$  of Bitmap-N<sub>C</sub> indicates the number of bits onto the  $(i - 32)$ -th upstream carrier in NEXT<sub>C</sub> symbols;  $g_i$  of Bitmap-N<sub>C</sub> indicates the scale factor that shall be applied to the  $(i - 32)$ -th upstream carrier in NEXT<sub>C</sub> symbols.

Because no bits or energy will be transmitted at dc or one-half the sampling rate,  $b_0, g_0, b_{32}, g_{32}, b_{64},$  and  $g_{64}$  are all presumed to be zero and shall not be transmitted.

The C-B&G information shall be mapped in a 992-bit (124 byte) message  $m$  defined by:

$$m = \{m_{991}, m_{990}, \dots, m_1, m_0\} = \{g_{63}, b_{63}, \dots, g_{33}, b_{33}, g_{31}, b_{31}, \dots, g_1, b_1\},$$

with the MSB of  $b_i$  and  $g_i$  in the higher  $m$  index and  $m_0$  being transmitted first. The message  $m$  shall be transmitted in 124 symbols, using the transmission method as described in 11.11.9.

When Bitmap-N<sub>C</sub> is disabled (FEXT Bitmap mode),  $b_i$  and  $g_i$  of Bitmap-N<sub>C</sub> shall be set to zero.

#### **C.8.7.3 C-SEGUE3 (supplements 11.11.16)**

The duration of C-SEGUE3 is 18 symbols. Following C-SEGUE-3, ATU-C completes the initialization and enters C-SHOWTIME. In C-SHOWTIME, ATU-C shall transmit the signal using Bitmap-F<sub>R</sub> and Bitmap-N<sub>R</sub> with the sliding window.

### **C.8.8 Exchange – ATU-R (supplements 11.12)**

The ATU-R shall transmit only the FEXT<sub>C</sub> symbols in R-MSG<sub>n</sub>, R-RATES<sub>n</sub>, R-B&G, R-CRC<sub>n</sub>. In other signals, the ATU-R shall transmit both FEXT<sub>C</sub> and NEXT<sub>C</sub> symbols when Bitmap-N<sub>C</sub> is enabled (Dual Bitmap mode) and shall not transmit NEXT<sub>C</sub> symbols when Bitmap-N<sub>C</sub> is disabled (FEXT Bitmap mode). The duration of each state is defined in Figure C.19.

**C.8.8.1 R-MSG-RA (related to 11.12.2)****C.8.8.1.1 Total number of bits supported ( $B_{\max}$ ) (replaces 11.12.2.7)**

This parameter shall be defined as in R-MSG2; see C.8.8.2.

**C.8.8.2 R-MSG2 (supplements 11.12.8)****C.8.8.2.1 Total number of bits per symbol supported (supplements 11.12.8.4)**

The maximum number of bits per symbol is defined at the reference point B, that is calculated from the  $FEXT_R$  and  $NEXT_R$  downstream channel performance.

**C.8.8.3 R-B&G (replaces 11.12.14)**

The purpose of R-B&G is to transmit to ATU-C the bits and gains information, Bitmap- $F_R$   $\{b_1, g_1, b_2, g_2, \dots, b_{255}, g_{255}\}$ , and Bitmap- $N_R$   $\{b_{257}, g_{257}, b_{258}, g_{258}, \dots, b_{511}, g_{511}\}$ , to be used on the downstream subcarriers.  $b_i$  of Bitmap- $F_R$  indicates the number of bits to be coded by ATU-C transmitter onto the  $i$ -th downstream subcarrier in  $FEXT_R$  symbols;  $g_i$  of Bitmap- $F_R$  indicates the scale factor that shall be applied to the  $i$ -th downstream subcarrier in  $FEXT_R$  symbols, relative to the gain that was used for that carrier during the transmission of C-MEDLEY. Similarly,  $b_i$  of Bitmap- $N_R$  indicates the number of bits onto the  $(i - 256)$ -th downstream carrier in  $NEXT_R$  symbols;  $g_i$  of Bitmap- $N_R$  indicates the scale factor that shall be applied to the  $(i - 256)$ -th downstream carrier in  $NEXT_R$  symbols. Because no bits or energy will be transmitted at DC or one-half the sampling rate,  $b_0, g_0, b_{256}, g_{256}, b_{512},$  and  $g_{512}$  are all presumed to be zero, and are not transmitted. Because subcarrier 64 is reserved as the pilot tone,  $b_{64}$  and  $b_{320}$ , shall be set to 0,  $g_{64}$  and  $g_{320}$  shall be set to  $g_{\text{sync}}$ . The value  $g_{\text{sync}}$  represents the gain scaling applied to the sync symbol.

The R-B&G information shall be mapped in a 8160-bit (1020 byte) message  $m$  defined by:

$$m = \{m_{8159}, m_{8158}, \dots, m_1, m_0\} = \{g_{511}, b_{511}, \dots, g_{257}, b_{257}, g_{255}, b_{255}, \dots, g_1, b_1\},$$

with the MSB of  $b_i$  and  $g_i$  in the higher  $m$  index and  $m_0$  being transmitted first. The message  $m$  shall be transmitted in 1020 symbols, using the transmission method as described in 11.12.8.

Values of  $b_i$  and  $g_i$  shall be set to 0 for values of  $127 < i < 256$ , and  $383 < i < 512$ .

When Bitmap- $N_R$  is disabled (FEXT Bitmap mode),  $b_i$  and  $g_i$  of Bitmap- $N_R$  shall be set to zero.

**C.8.8.4 R-SEGUE5 (replaces 11.12.17)**

The duration of R-SEGUE5 is 13 symbols. Following R-SEGUE-5, ATU-R completes the initialization and enters R-SHOWTIME. In R-SHOWTIME, ATU-R shall transmit the signal using Bitmap- $F_C$  and Bitmap- $N_C$  with the sliding window.

**C.9 Fast retraining (supplements clause 12)**

The definition of Fast Retrain procedure is the same as main body except for the definition of C-RECOV, the introduction of R-RECOV2, and duration of symbols which includes the Sliding Window operation. The definition of C-RECOV and R-RECOV2 are defined in C.9.2. The duration of each state is defined in Figure C.22.



**C.9.1 Fast Retrain overview (pertains to 12.1)****C.9.1.1 Profile requirement (supplements 12.1.1)**

B&G tables of profile contain both Bitmap- $F_R$  and Bitmap- $N_R$  in the ATU-C, and both Bitmap- $F_C$  and Bitmap- $N_C$  in the ATU-R.

**C.9.2 Definition of Fast Retrain signals (supplements 12.2)**

C-RECOV signal is changed and the signal R-RECOV2 is added.

- C-RECOV consists of a single tone signal corresponding to subcarrier 68 without cyclic prefix accompanied by the C-PILOT1 signal which contains subcarrier 64 and 48 (see C.8.3.1). ATU-C shall transmit the signal which includes 64, 68 and 48th subcarrier as FEXT $_R$  symbol, and shall transmit the signal which includes 64 and 48th subcarrier as NEXT $_R$  symbol. This signal allows the ATU-R to perform or maintain timing recovery and hyperframe synchronization.
- R-RECOV2 is single tone signal corresponding to subcarrier 22 without cyclic prefix. The PSD level to be used for R-RECOV2 shall be the same as R-RECOV. ATU-R transmits R-RECOV2 both FEXT $_R$  and NEXT $_R$  symbols.

**C.9.3 Fast Retrain procedure (supplements 12.3)****C.9.3.1 ATU-C initiated from SHOWTIME (supplements 12.3.1)**

Figures C.20 and C.21 show the timing diagrams for the Fast Retrain with the ATU-C initiating the procedure.

Time-outs C-TO2, C-TO3, R-TO1, R-TO3 are vendor discretionary. It is advisable to make these durations as short as possible.

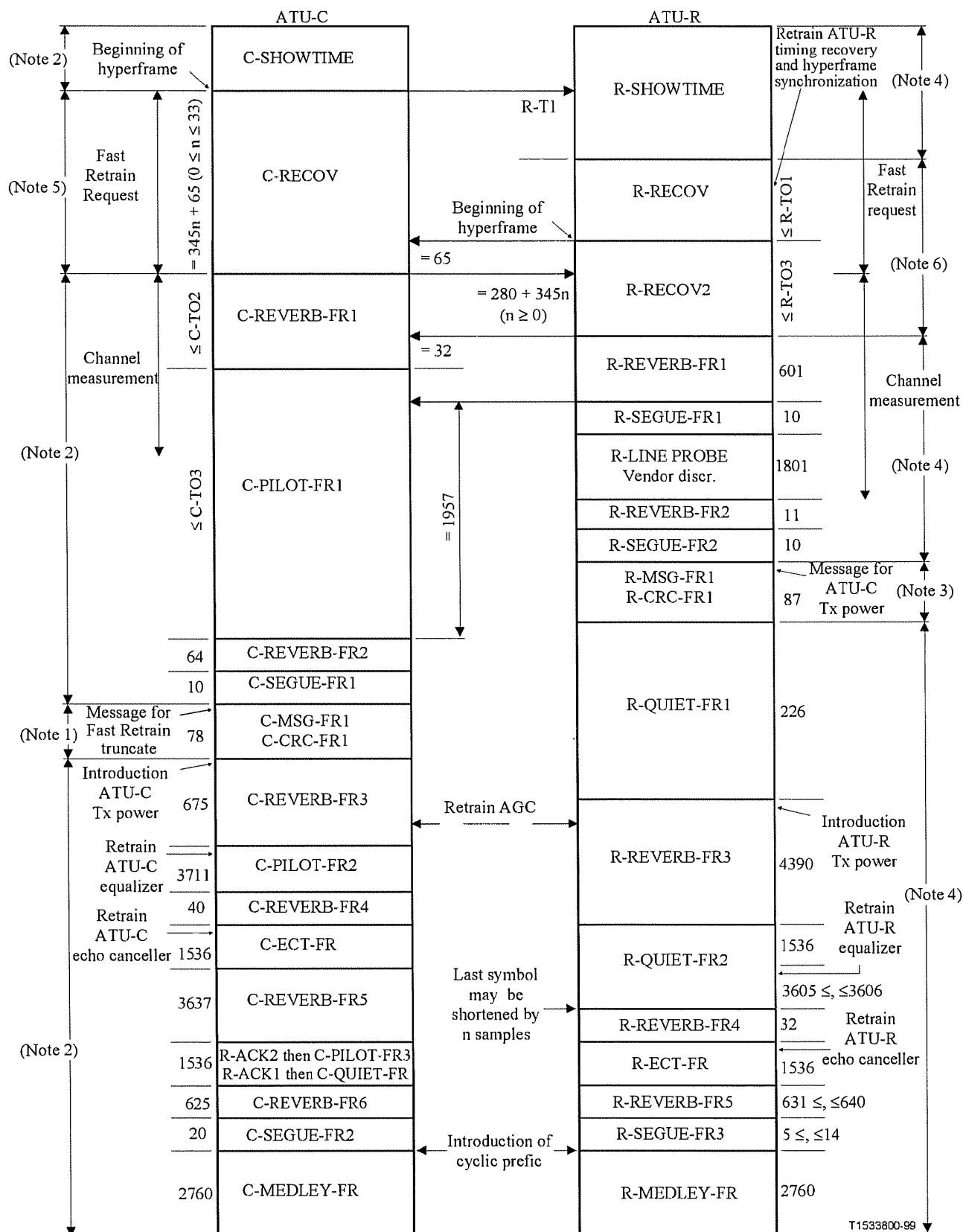
The following issues are different from main body and transition state timing is similar to initialization (see C.8).

- The ATU-C shall enter C-RECOV at the beginning of the hyperframe without cyclic prefix.
- The ATU-C shall transmit the pilot tone as the NEXT $_R$  symbols in C-MSG-n and C-CRC-n.
- When Bitmap- $N_R$  is disabled (FEXT Bitmap mode) in preceding SHOWTIME, the ATU-C shall transmit the pilot tone as NEXT $_R$  symbols, except C-RECOV and C-QUIET-FR.
- The ATU-C enters C-MEDLEY-FR at the beginning of the hyperframe with cyclic prefix.
- The ATU-R shall enter R-RECOV2 at the beginning of the hyperframe without cyclic prefix after the synchronization of ADC clock with the received C-RECOV signal. Last symbol of R-RECOV may be shortened.
- The ATU-R shall not transmit any signal as the NEXT $_C$  symbols in R-MSG-n and R-CRC-n.
- When Bitmap- $N_C$  is disabled (FEXT Bitmap mode) in preceding SHOWTIME, the ATU-R shall not transmit the NEXT $_C$  symbols, except R-RECOV and R-RECOV2.
- The ATU-R enters R-MEDLEY-FR at the beginning of the hyperframe with cyclic prefix.

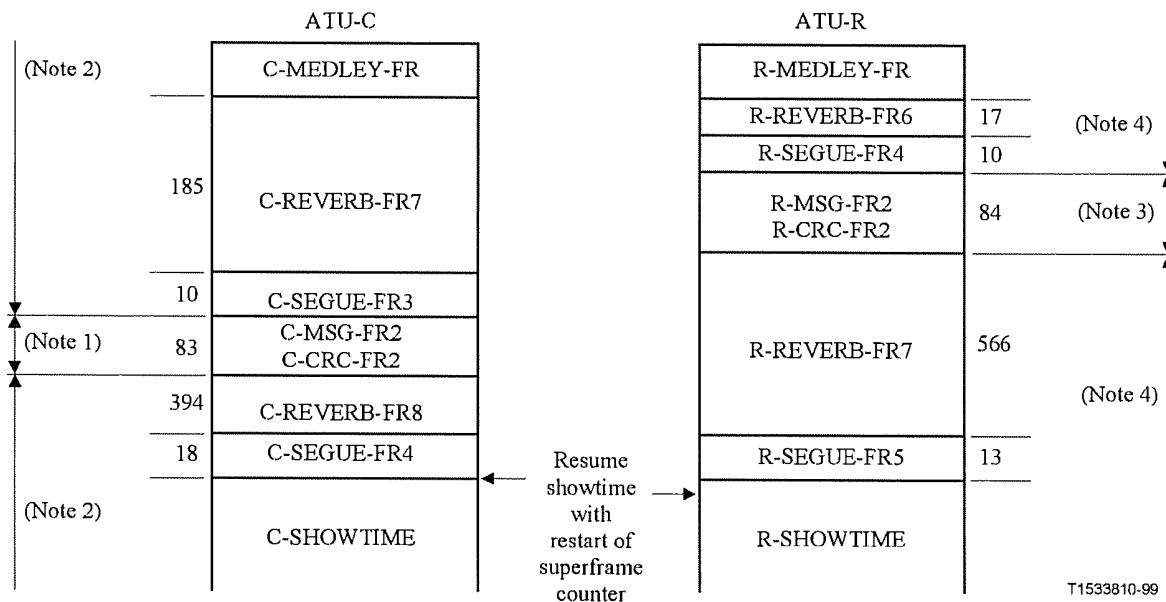
**C.9.3.2 ATU-R initiated from SHOWTIME (supplements 12.3.2)**

Figure C.22 shows the timing diagram for the Fast Retrain with the ATU-R initiating the procedure.

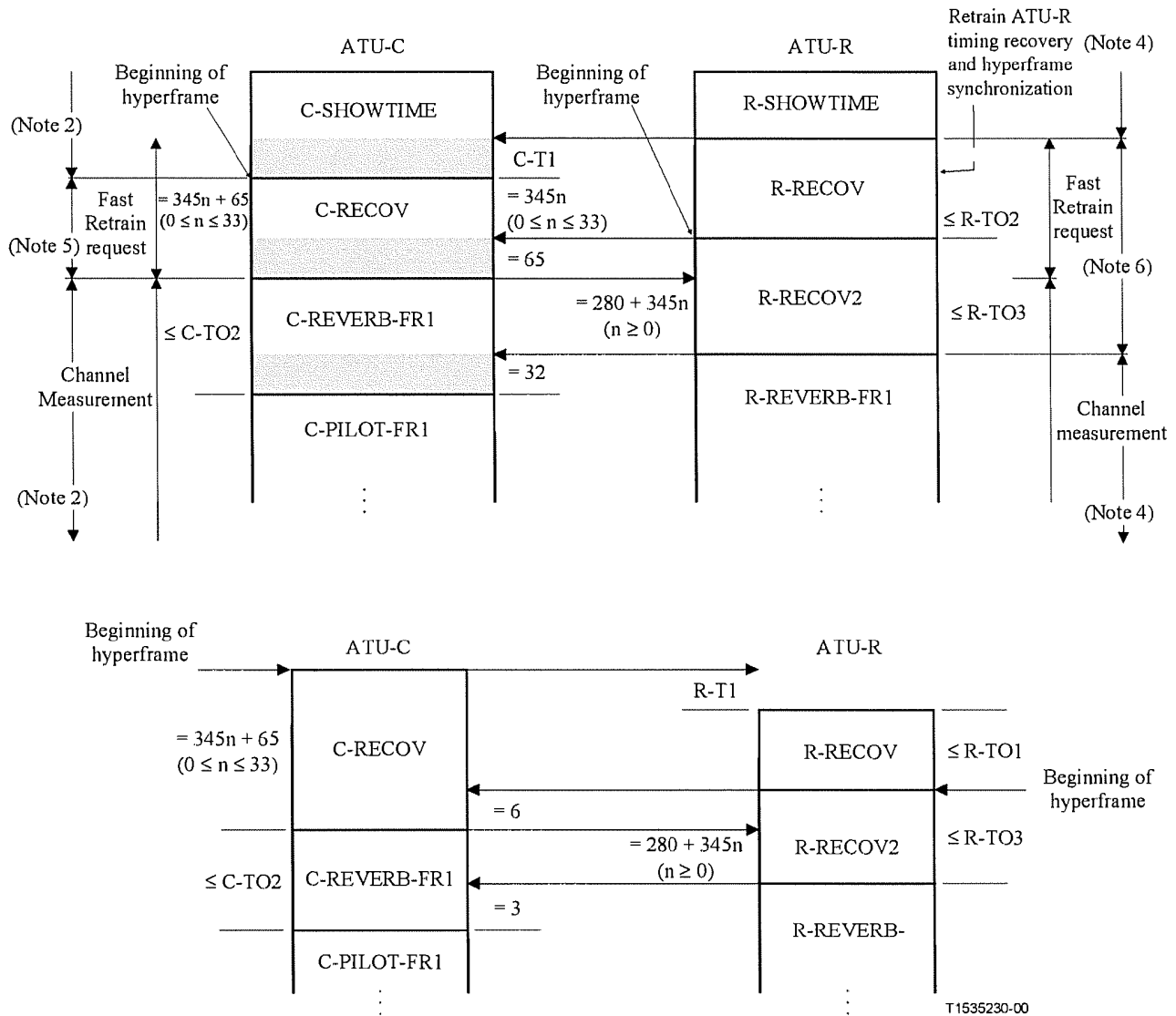
Time-outs C-TO2, R-TO2, R-TO3 are vendor discretionary. It is advisable to make these durations as short as possible.



**Figure C.20/G.992.2 – Timing diagram of the Fast Retrain procedure, ATU-C initiated from  
SHOWTIME (part 1)**



**Figure C.21/G.992.2 – Timing diagram of the Fast Retrain procedure, ATU-C initiated from SHOWTIME (part 2)**



**Figure C.22/G.992.2 – Timing diagram of the Fast Retraining procedure, ATU-R initiated from SHOWTIME**

#### Notes to Figures C.21 and C.22

NOTE 1 – ATU-C shall transmit the  $FEXT_R$  symbols, and shall not transmit the  $NEXT_R$  symbols except pilot tone.

NOTE 2 – ATU-C shall transmit both  $FEXT_R$  and  $NEXT_R$  symbols, when Bitmap- $N_R$  is enabled (Dual Bitmap mode). ATU-C shall not transmit the  $NEXT_R$  symbols except pilot tone, when Bitmap- $N_R$  is disabled (FEXT Bitmap mode).

NOTE 3 – ATU-R shall transmit the  $FEXT_C$  symbols, and shall not transmit the  $NEXT_C$  symbols.

NOTE 4 – ATU-R shall transmit both  $FEXT_C$  and  $NEXT_C$  symbols, when Bitmap- $N_C$  is enabled (Dual bitmap mode). ATU-R shall not transmit  $NEXT_C$  symbols, when Bitmap- $N_C$  is disabled (FEXT Bitmap mode).

NOTE 5 – ATU-C shall transmit both  $FEXT_R$  and  $NEXT_R$  symbols. However, the transmission signal is different between  $FEXT_R$  and  $NEXT_R$  symbol (see C.9.2).

NOTE 6 – ATU-R shall transmit both  $FEXT_C$  and  $NEXT_C$  symbols.

**C.9.4 Initiated from L3 or Recommendation G.994.1 (replaces 12.5)**

A Fast Retrain Procedure initiated from an idle link state or via an Escape from Handshake shall be according to C.9.3.1 or C.9.3.2 except for a longer time duration for R-TO1 or R-TO2 of the R-RECOV signal. This will allow for re-acquisition of loop timing and hyperframe synchronization with the received C-RECOV signal at the ATU-R.

**C.10 Power management (pertains to clause 13)****C.10.1 Transition from L0 to L1 (T0d) (pertains to 13.4.2)****C.10.1.1 Exchange entry procedure (replaces 13.4.2.1)**

This subclause defines the Exchange entry procedure. This procedure reuses states, signals, and rules for determining the next state contained within C.8.6 as defined in the following steps.

- 1) After successful termination of the eoc handshake procedure, the ATU-R shall start R-QUIET-PM at the Hyperframe boundary. R-QUIET-PM is defined as no transmitted signal onto the U-R interface. The ATU-R shall maintain loop timing and Hyperframe synchronization during the R-QUIET-PM signal.
- 2) After the detection of R-QUIET-PM, the ATU-C shall start C-REVERB4 at next 287th symbol (frame 286) of the hyperframe. In this procedure, the duration of C-REVERB4 is  $345n - 304$  ( $3 \leq n \leq 9$ ).
- 3) After the detection of C-REVERB4, the ATU-R responds by sending R-REVERB4 at next 37th symbol (frame 36) of the hyperframe. The exchange portion of the initialization procedure defined in C.8.6 shall continue from this point (i.e. the ATU-R shall send R-SEGUE after 296 symbols of R-REVERB4). During R-MSG-RA, the ATU-R shall use the "no options selected" message. The ATU-C implementation shall include a means that blocks the loss of signal defect during exchange entry procedure.

**ANNEX D****System performance for North America****D.1 System performance for North America**

All test cases specified in this annex shall be used for the main body of this Recommendation and testing shall conform to the following:

- No power cutback on upstream transmitter.
- Margin = 4 dB.
- $BER = 10^{-7}$ .
- Background noise = -140 dBm/Hz.
- Data rates, except where noted, are to be measured in the absence of a customer premises wiring.
- Data rates listed are the net payload data rate. (ATM cell overhead is included within the listed bit rates, but framing, eoc, and RS code overheads are not included within the listed bit rates.)
- For testing purposes, one-way payload transfer delay shall be less than  $10 + (S \times D)/4$  ms.
- Loop environmental temperature = 25° C.

A Recommendation G.992.2 Annex D compliant system (ATU-C and ATU-R) shall meet the following minimum performance requirements:



**D.1.1 Required test cases****Table D.1/G.992.2 – Required test cases**

Case #	Loop	Downstream net data rate	Upstream net data rate	Noise
1	Null Loop	1536 kbit/s	512 kbit/s	None
2	T #7	1536 kbit/s	224 kbit/s	49 Annex A/G.992.2
3	T #7	1536 kbit/s	224 kbit/s	24 DSL
4	T #13	1184 kbit/s	224 kbit/s	49 Annex A/G.992.2
5	T #13	1184 kbit/s	224 kbit/s	24 DSL
6	Shortened T #7	1184 kbit/s	256 kbit/s	10 HDSL
7	Shortened T #7	512 kbit/s	512 kbit/s	5 adjacent binder T1
8	T #8	256 kbit/s	96 kbit/s	24 Annex A/G.992.2
9	T #8	256 kbit/s	96 kbit/s	10 DSL
10	T #13 In-home wiring model #1 G.996.1	768 kbit/s	192 kbit/s	49 Annex A/G.992.2
11	T #13 In-home wiring model #1 G.996.1	768 kbit/s	192 kbit/s	24 DSL

In addition to the above loops, a Recommendation G.992.2 Annex D compliant system (ATU-C and ATU-R) should meet the following performance points in order to provide extended loop reach.

**D.1.2 Extended reach cases**

For the extended reach test cases #12 and #13 margin testing shall be performed without the check that the ADSL unit can train at the 4 dB margin level.

**Table D.2/G.992.2 – Extended reach test cases**

Case #	Loop	Downstream net data rate	Upstream net data rate	Noise
12	T #1	256 kbit/s	96 kbit/s	3 Annex A/G.992.2
13	T #2	256 kbit/s	96 kbit/s	24 Annex A/G.992.2
14	T #5	768 kbit/s	256 kbit/s	49 Annex A/G.992.2
15	T #5	768 kbit/s	256 kbit/s	24 DSL
16	T #9	1536 kbit/s	256 kbit/s	49 Annex A/G.992.2
17	T #9	1536 kbit/s	256 kbit/s	24 DSL
18	Shortened T #7	1536 kbit/s	256 kbit/s	24 HDSL

NOTE 1 – A goal of future enhancements of this Recommendation is to make the "Extended Reach Cases" mandatory.

NOTE 2 – Performance levels do not reflect the effect of customer premise wiring, which is expected to reduce data rate.

## ANNEX E

**System performance for Europe****E.1 System performance for Europe**

This annex specifies European performance requirements for this Recommendation over short, medium and long loops without inclusion of premises wiring or phone models.

The one-way payload transfer delay shall be below  $10 + (S \times D)/4$  ms for the ADSL Line (excluding ATM TC).

The performance points in Table E.1 must be met with a BER of  $10^{-7}$  at 6 dB margin. The ATU-C and ATU-R shall be connected directly via the specified loop (no home network or phone model present).

**Table E.1/G.992.2 – Proposed European required Test Loops and Performance Targets for G.992.2 FDM and overlapped spectrum implementations**

Case #	Loop (see Rec. G.996.1)	Loop Insertion loss @ 300 kHz	Nominal length (km)	Down net data rate (kbit/s)	Up net data rate (kbit/s)	Noise @ ATU-C	Noise @ ATU-R
1	ETSI-0	0 dB	0	1536	512	No	No
2	ETSI-1	40 dB	2.80	1536	256	Euro-K	ETSI-A
3	ETSI-1	50 dB	3.50	1536	96	Euro-K	ETSI-A
4	ETSI-1	40 dB	2.80	1536	448	ETSI-A	ETSI-A
5	ETSI-1	50 dB	3.50	1536	256	ETSI-A	ETSI-A
6	ETSI-1	60 dB	4.20	512	96	ETSI-A	ETSI-A
7	ETSI-1	60 dB	4.20	1536	512	AWGN-140	AWGN-140

## APPENDIX I

In anticipation of future revisions of this Recommendation, manufacturers are encouraged to implement and investigate the performance of trellis coding in a splitterless environment as defined in Recommendation G.992.1.

Implementers wishing to investigate the use of trellis coding should negotiate its use via the Non-Standard Facilities (NSF) capabilities of Recommendation G.994.1.

## APPENDIX II

**Guide to scenarios for the implementation of the various procedures in  
Recommendations G.994.1 and G.992.2**

**Scope**

This informative appendix is intended to guide implementers through multiple scenarios of using Recommendation G.994.1 and this Recommendation together in an implementation. The scenarios exemplify procedures that conform to Recommendation G.994.1 and this Recommendation. The scenarios are not intended to limit Recommendation G.994.1 and this Recommendation but rather are intended to assist implementers in understanding the relationship between the various procedures defined in Recommendations G.994.1 and G.992.2.

**Definitions and abbreviations**

UC	G.992.2 Absolute Upstream Fast Retrain Power Cutback, transmitted by the CP in the R-MSG-FR1 bits $u_4$ - $u_0$ .
RDC	G.992.2 Relative Downstream Fast Retrain Power Cutback, transmitted by the CP in the R-MSG-FR1 bits $d_4$ - $d_0$ .
DPI	G.992.2 Initialization Politeness Power Cutback, transmitted by the CO in the C-MSG1 bits 8-6.
DPF	G.992.2 Fast Retrain Politeness Power Cutback, transmitted by the CO in the C-MSG-FR1 bits $b_4$ - $b_0$ .
UMAX	G.994.1 maximum power for an upstream signal, defined in Recommendation G.994.1.
DMAX	G.994.1 maximum power for a downstream signal, defined in Recommendation G.994.1.
$g_i$	G.992.2 Gain scaling values applied during modulation in either the upstream or downstream direction.

In the definitions of acronyms above, the letters U and D of the acronyms represent upstream and downstream, respectively. The letter R represents relative, and the letter C represents cutback. The letters I and F represent initialization and "fast retrain," respectively.

**Note on the use of PSD level**

This appendix often describes PSD levels of particular signals in either G.992.2 or G.994.1. In all cases, the PSD level described should be referenced back to the defining document to determine the exact method of measuring the power.

For signals that are composed of single or multiple continuous subcarriers, the PSD level must be interpreted as a power number per subcarrier rather than a density. For G.992.2 maximum levels, Table II.1 should be used (). Other cutback values for G.992.2 and G.994.1 have similar relationship between the PSD level and the power per subcarrier.

**Table II.1/G.992.2 – PSD level and power per Subcarrier**

PSD Level	Power
-38 dBm/Hz	-1.65 dBm/subcarrier
-40 dBm/Hz	-3.65 dBm/subcarrier

## Scenarios

The scenarios included in this appendix are organized into several categories for convenience. Each scenario is presented with a list of successive steps the ATU pair might execute. These steps are examples only and do not provide an exhaustive listing of all allowable steps.

Each scenario is also presented in a timeline similar to those used in the main body of this Recommendation. The timeline shows the progression of ATU states, power levels used at each transmitter, and references to the appropriate clauses of Recommendation G.994.1 and this Recommendation.

Following the timeline of some scenarios that invoke various power cutback levels, hypothetical examples are provided to illustrate various conditions that effect the scenario's power cutback levels.

### Activation scenarios

These scenarios represent situations in which the ADSL link is activated with one or the other end having no memory of any prior activation.

#### First Successful On-hook Activation

This scenario describes a sequence that might occur during the first activation of the ADSL link from power management states L3 to L0. Both ATUs are assumed installed and ready to operate. The ATUs have no memory of past activation.

For convenience in describing the scenario, the ATU state sequence is broken into several blocks as given in Table II.2. The step numbers in the table refer to the paragraph numbers that follow in this subclause.

**Table II.2/G.992.2 – Blocks of First Successful On-Hook Activation Scenario**

Block	Steps
First G.994.1	1-3
Aborted Fast Retrain	4-5
Second G.994.1	6-8
Second Fast Retrain	9-13
Third G.994.1	14-16
Initialization Procedure	17-21
SHOWTIME	22

The scenario proceeds as described in the following steps and as depicted in Figure II.1. The duration of states C-SILENT1 and R-SILENT0 described in this section and as shown in Figure II.1 may be unnoticeably small at the receiving ATU.

CO Transmitter Downstream				CP Transmitter Upstream	
dbm/Hz	State	Block	Step	dbm/Hz	State
n/a	CSILENT-1	First G.994.1	1	n/a	RSILENT-0
$\leq \text{DMAX}$	C-TONES		2	$\leq \text{UMAX}$	R-TONES-REQ
$\leq \text{DMAX}$ (same)	various G.994.1 states ending in C-FLAG2		3	$\leq \text{UMAX}$ (same)	various G.994.1 states ending in R-FLAG2
n/a	C-QUIET-EF1	Aborted Fast Retrain	4	n/a	R-QUIET-EF1
-40	C-RECOV		5		
n/a	C-SILENT1	Second G.994.1	6		
-40	C-TONES		7	-38	R-TONES-REQ
-40	various G.994.1 states ending in C-FLAG2		8	-38	various G.994.1 states ending in R-FLAG2
n/a	C-QUIET-EF1	Second Fast Retrain	9	n/a	R-QUIET-EF1
-40	C-RECOV		10		
-40 - DPF	C-REVERB-FR1		11	-38	R-RECOV
-40 - DPF	sequence of fast retrain states ending in C-CRC-FR1		12		
			13	$\leq -38$	sequence of fast retrain states ending in R-QUIET-FR1
n/a	C-SILENT1	Third G.994.1	14	n/a	R-SILENT0
-40	C-TONES		15	-38 - UC	R-TONES-REQ
-40 - DPF - RDC	various G.994.1 states ending in C-FLAG2		16	-38 - UC	various G.994.1 states ending in R-FLAG2
n/a	C-QUIET2	Initialization Procedure	17	n/a	R-QUIET2
-40 - DPF - RDC	C-PILOT1		18		
-40	C-REVERB1		19	-38	R-REVERB1
- max (DPI, DPF + RDC)			20	- UC	
-40	sequence of initialization states ending in C-SEGUE3		21	-38 - UC	sequence of initialization states ending in R-SEGUE5
-40 - max (DPI, DPF + RDC) $+ g_i$	SHOWTIME	SHOWTIME	22	-38 - UC $+ g_i$	SHOWTIME

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Figure II.1/G.992.2 – First time activation scenario

**First G.994.1**

- 1 The ATU-R initiates G.994.1 by transmitting R-TONES-REQ at no greater than the maximum G.994.1 power level for upstream (UMAX).
- 2 The ATU-C responds with G.994.1 by transmitting C-TONES at no greater than the maximum G.994.1 power level for downstream (DMAX).



- 3 Both ATUs continue the G.994.1 procedure using the same power levels and terminate the G.994.1 procedure using a mode select transaction with a G.992.2 code point asserted and the escape to fast retrain bit asserted.

#### **Aborted Fast Retrain**

- 4 Both ATUs observe the quiet period requirement of the escape to fast retrain procedure.
- 5 The ATU-C initiates the fast retrain procedure by transmitting the C-RECOV signal at -40 dBm/Hz.

#### **Second G.994.1**

- 6 The ATU-R aborts the fast retrain by again transmitting R-TONES-REQ at -38 dBm/Hz so that the G.994.1 procedures will be repeated at nominal power levels specified by G.992.2 to facilitate average power level measurement at the CO.
- 7 The ATU-C restarts G.994.1 by transitioning to C-SILENT1 and transmitting C-TONES at -40 dBm/Hz level.
- 8 Both ATUs continue with G.994.1 procedure using the same power levels and again terminate using a mode select transaction with a G.992.2 code point asserted and the escape to fast retrain bit asserted. The ATU-C measures the G.994.1 average received power per tone during the procedure.

#### **Second Fast Retrain**

- 9 Both ATUs observe the quiet period requirement of the escape to fast retrain procedure.
- 10 The ATU-C initiates the fast retrain procedure by transmitting C-RECOVER signal at -40 dBm/Hz.
- 11 The ATU-R responds with the fast retrain procedure by transmitting the R-RECOV signal at -38 dBm/Hz, and the ATU-C measures the received power. This power measurement and the measurements made during G.994.1 are combined in a vendor discretionary manner at the CO to form an "average". The "average" is used by the ATU-C to determine the fast retrain politeness power cutback (DPF) of 0, 2, 4, 6, 8, 10, or 12 dB.
- 12 ATU-C continues the fast retrain procedure by transmitting C-REVERB-FR1 at -40 - DPF dBm/Hz.
- 13 Both ATUs truncate the fast retrain procedure using the bits in R-MSG-FR1 and C-MSG-FR1. The ATU-C transmits at a power level of -40 - DPF dBm/Hz. The ATU-R transmits at a single vendor discretionary power level less than or equal to -38 dBm/Hz. During the messages exchanged in this fast retrain procedure, the ATU-R commands the ATU-C of the relative downstream power fast retrain power cutback (RDC) that shall be used and informs the ATU-C of the absolute upstream fast retrain power cutback (UC) that it shall use. The ATU-C informs the ATU-R of the fast retrain politeness cutback (DPF) that was used during the fast retrain procedure.

#### **Third G.994.1**

- 14 The ATU-R initiates G.994.1 by transitioning to R-SILENT0 and transmitting R-TONES-REQ at -38 - UC dBm/Hz.
- 15 The ATU-C responds with G.994.1 by transitioning to C-SILENT1 and transmitting C-TONES at -40 - DPF - RDC dBm/Hz.
- 16 Both ATUs continue with the G.994.1 procedure and terminate it using a mode select transaction with a G.992.2 code point asserted (and the escape to fast retrain bit is not asserted).

**Initialization Procedure**

- 17 Both ATUs observe the quiet period required at the start of the G.992.2 initialization procedure.
- 18 The ATU-C continues the initialization procedure by transmitting C-PILOT at  $-40 - \text{DPF} - \text{RDC}$  dBm/Hz.
- 19 The ATU-R responds by transmitting R-REVERB1 at  $-38 - \text{UC}$  dBm/Hz, and the ATU-C measures the received power in 12 tones to determine a new initialization politeness power cutback (DPI) of 0, 2, 4, 6, 8, 10, or 12 dB.
- 20 The ATU-C starts transmitting C-REVERB1 at  $-40 - 2n$ . The value of  $2n$  is the maximum of the value of  $(\text{DPF} + \text{RDC})$  and the value of DPI.
- 21 Both ATUs finish the initialization procedure and go to SHOWTIME. During the messages exchanged in this initialization procedure, the ATU-C informs the ATU-R of the value of DPI that was determined (but the value  $2n$  is the absolute power cutback used by the ATU-C). Both ATUs signal that they have lost all profiles, and both ATU erase any profile information currently stored.

**SHOWTIME**

- 22 During SHOWTIME, both ATUs save profile #0 using the aoc protocol. The ATU-C transmits at  $-40 - 2n$  dBm/Hz. The ATU-R transmits at  $-38 - \text{UC}$  dBm/Hz.

This scenario conforms to G.992.2 for all cases of short and long loops, on-hook and off-hook conditions, and with or without in-line filters. However, the effect of power cutback varies considerably in each of these cases. Several examples are provided to clarify the effect of power cutback in these cases. Each example is summarized with a table that depicts the same state flow of both ATUs as shown in Figure II.1. The template for the example is shown in Table II.3.

**Table II.3/G.992.2 – Summary of First Time Install Scenario**

ATU-C Block	dBm/Hz	Steps	ATU-R Block	dBm/Hz
First G.994.1	$\leq \text{DMAX}$	1 -3	First G.994.1	$\leq \text{UMAX}$
Aborted First Fast Retrain	$-40$	4-5	N/A	
Second G.994.1	$-40$	6-8	Second G.994.1	$-38$
Second Fast Retrain C-RECOV	$-40$	9-11	Second Fast Retrain R-RECOV	$-38$
Remainder of Second Fast Retrain	$-40 - \text{DPF}$	12-13	Remainder of Second Fast Retrain	$\leq -38$
Third G.994.1	$-40 - \text{DPF} - \text{RDC}$	14-16	Third G.994.1	$-38 - \text{UC}$
C-PILOT	$-40 - \text{DPF} - \text{RDC}$	17-19	R-REVERB1	$-38 - \text{UC}$
C-REVERB1 and Remainder of Initialization Procedure	$-40 - \max(\text{DPI}, \text{DPF} + \text{RDC})$	20-21	Remainder of Initialization Procedure	$-38 - \text{UC}$
SHOWTIME	$-40 - \max(\text{DPI}, \text{DPF} + \text{RDC}) + g_i$	22	SHOWTIME	$-38 - \text{UC} + g_i$

**Example with Long Loop and In-line Filters**

During the scenario in this example with long loops and no effect from telephony devices, there will be no politeness or fast retrain power cutbacks. A numeric example of the various power levels is summarized in Table II.4.

**Table II.4/G.992.2 – Power Levels for Install Case with Long Loop with In-Line Filters**

ATU-C Block	dBm/Hz	ATU-R Block	dBm/Hz
First G.994.1	$\leq \text{DMAX}$	First G.994.1	$\leq \text{UMAX}$
Aborted First Fast Retrain	-40	N/A	
Second G.994.1	-40	Second G.994.1	-38
Second Fast Retrain C-RECOV	-40	Second Fast Retrain R-RECOV	-38
Remainder of Second Fast Retrain	-40	Remainder of Second Fast Retrain	$\leq -38$
Third G.994.1	-40	Third G.994.1	-38
C-PILOT	-40	R-REVERB1	-38
C-REVERB1 and Remainder of Initialization Procedure	-40	Remainder of Initialization Procedure	-38
SHOWTIME	$-40 + g_i$	SHOWTIME	$-38 + g_i$

**Example with Short Loop and In-line Filters**

During the scenario in this case, the two politeness cutbacks will be active and there will be no fast retrain power cutback. A numeric example of the various power levels is shown in Table II.5. In this example, the value of DPF is 10 dB, and the value of DPI is 12 dB.

**Table II.5/G.992.2 – Power Levels for Install Case with Short Loop with In-Line Filters**

ATU-C Block	dBm/Hz	ATU-R Block	dBm/Hz
First G.994.1	$\leq \text{DMAX}$	First G.994.1	$\leq \text{UMAX}$
Aborted First Fast Retrain	-40	N/A	
Second G.994.1	-40	Second G.994.1	-38
Second Fast Retrain C-RECOV	-40	Second Fast Retrain R-RECOV	-38
Remainder of Second Fast Retrain	-50	Remainder of Second Fast Retrain	$\leq -38$
Third G.994.1	-40	Third G.994.1	-38
C-PILOT	-40	R-REVERB1	-38
C-REVERB1 and Remainder of Initialization Procedure	-52	Remainder of Initialization Procedure	-38
SHOWTIME	$-52 + g_i$	SHOWTIME	$-38 + g_i$

**Example with Short Loop and Non-ideal Telephone Devices**

During the scenario in this case, the politeness power cutbacks will be active and there will be fast retrain power cutbacks in each direction. A numeric example of the various power levels is shown in Table II.6. In this example, the value of DPF is 4 dB, and the value of DPI is 2 dB. The values of RDC and UC are 12 and 10 dB, respectively.

**Table II.6/G.992.2 – Power Levels for Install Case with Short Loop  
with Non-ideal Telephone Devices**

ATU-C Block	dBm/Hz	ATU-R Block	dBm/Hz
First G.994.1	$\leq \text{DMAX}$	First G.994.1	$\leq \text{UMAX}$
Aborted First Fast Retrain	-40	N/A	
Second G.994.1	-40	Second G.994.1	-38
Second Fast Retrain C-RECOV	-40	Second Fast Retrain R-RECOV	-38
Remainder of Second Fast Retrain	-44	Remainder of Second Fast Retrain	$\leq -38$
Third G.994.1	-56	Third G.994.1	-48
C-PILOT	-56	R-REVERB1	-48
C-REVERB1 and Remainder of Initialization Procedure	-56	Remainder of Initialization Procedure	-48
SHOWTIME	$-56 + g_i$	SHOWTIME	$-48 + g_i$

**Example with Long Loop and Non-ideal Telephone Devices**

During the scenario in this case, there will be no politeness cutbacks but there will be fast retrain power cutbacks in each direction. A numeric example of the various power levels is shown in Table II.7. In this example, the value of RDC and UC are 4 and 12 dB, respectively.

**Table II.7/G.992.2 – Power Levels for Install Case with Long Loop  
with Non-ideal Telephone Devices**

ATU-C Block	dBm/Hz	ATU-R Block	dBm/Hz
First G.994.1	$\leq \text{DMAX}$	First G.994.1	$\leq \text{UMAX}$
Aborted First Fast Retrain	-40	N/A	
Second G.994.1	-40	Second G.994.1	-38
Second Fast Retrain C-RECOV	-40	Second Fast Retrain R-RECOV	-38
Remainder of Second Fast Retrain	-40	Remainder of Second Fast Retrain	$\leq -38$
Third G.994.1	-44	Third G.994.1	-50
C-PILOT	-44	R-REVERB1	-50
C-REVERB1 and Remainder of Initialization Procedure	-44	Remainder of Initialization Procedure	-50
SHOWTIME	$-44 + g_i$	SHOWTIME	$-50 - g_i$

**Normal Operating Scenarios**

These scenarios represent situations that will normally occur while operating in the SHOWTIME L0 and L1 link states.

**First Off-hook Condition**

This scenario describes a sequence that might occur during the first off-hook condition following activation of the ADSL link. Both ATUs are assumed to be operating in the SHOWTIME state. The ATUs have only profile #0 stored associated with the present SHOWTIME configuration. A non-ideal telephone device without an in-line filter is assumed to go to its off-hook state in this scenario.

For convenience in describing the scenario, the ATU state sequence is broken into several blocks as given in Table II.8. The step numbers in the table refer to the paragraph numbers that follow in this subclause.

**Table II.8/G.992.2 – Blocks of First Off-Hook Scenario**

Block	Steps
First SHOWTIME	
Fast Retrain	1-5
G.994.1	6-8
Initialization Procedure	9-13
Second SHOWTIME	14

The scenario proceeds as described in the steps below and as depicted in Figure II.2. The duration of states C-SILENT1 and R-SILENT0 described in this subclause and as shown in Figure II.2 may be unnoticeably small at the receiving ATU.



CO Transmitter Downstream				CP Transmitter Upstream	
dbm/Hz	State	Block	Step	dbm/Hz	State
$-40$ $- \max(DP_i',$ $DPF' + RDC')$ $+ g_i'$	SHOWTIME	First SHOWTIME		$-38$ $- UC$ $+ g_i'$	SHOWTIME
$-40$	C-RECOV		1		
$-40$ $- DPF'$	C-REVERB-FR1	Fast Retrain	2	$-38$	R-RECOV
$-40$ $- DPF'$	sequence of fast retrain states ending in C-CRC-FR1		3		
$-40$ $- DPF' - RDC'$	sequence of fast retrain states starting with C-REVERB-FR3 and ending in C-SEGUE-FR4		4	$\leq -38$	sequence of fast retrain states ending in R-QUIET-FR1
			5		sequence of fast retrain states starting with R-REVERB-FR3 and ending in R-SEGUE-FR5
$n/a$	C-SILENT1		6	$n/a$	R-SILENT0
$-40$ $- DPF' - RDC'$	C-TONES	G.994.1	7	$-38$ $- UC'$	R-TONES-REQ
$-40$ $- DPF' - RDC'$	various G.994.1 states ending in C-FLAG2		8	$-38$ $- UC'$	various G.994.1 states ending in R-FLAG2
$n/a$	C-QUIET2		9	$n/a$	R-QUIET2
$-40$ $- DPF' - RDC'$	C-PILOT1	Initialization Procedure	10		
$-40$ $- \max(DP_i',$ $DPF' + RDC')$	C-REVERB1		11	$-38$ $- UC'$	R-REVERB1
$-40$ $- \max(DP_i',$ $DPF' + RDC')$	sequence of initialization states ending in C-SEGUE3		12		
			13	$-38$ $- UC'$	sequence of initialization states ending in R-SEGUE5
$-40$ $- \max(DP_i',$ $DPF' + RDC')$ $+ g_i'$	SHOWTIME	Second SHOWTIME	14	$-38$ $- UC'$ $+ g_i'$	SHOWTIME

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Figure II.2/G.992.2 – First off-hook telephone scenario

**Fast Retrain**

- 1 The ATU-R initiates the fast retrain procedure by transmitting R-RECOV signal at  $-38$  dBm/Hz. In this example, the ATU-C does not measure the received power of the tone to calculate DPF as in the install scenario in First Successful On-hook Activation.
- 2 The ATU-C initiates the fast retrain procedure by transmitting C-RECOV signal at  $-40$  dBm/Hz.
- 3 The ATU-C transmits C-REVERB-FR1 at  $-40 - \text{DPF}$ . In this example, the ATU-C sets DPF to the previous value of DPI unlike the install scenario in First Successful On-hook Activation.
- 4 In this example, both ATUs execute the first portion of the fast retrain procedure (through C-CRC-FR1 and R-QUIET-FR1). The ATU-C transmits at a power level of  $-40 - \text{DPF}$  dBm/Hz. The ATU-R transmits at a single vendor discretionary power level of less than or equals  $-38$  dBm/Hz. During the messages exchanged in this fast retrain procedure, the ATU-R commands the ATU-C of the value of RDC that shall be used and informs the ATU-C of the value of UC that it shall use. The ATU-C informs the ATU-R of the value of DPF that it has been using.
- 5 Both ATUs complete the fast retrain procedure. The ATU-C transmits at a power level of  $-40 - \text{DPF} - \text{RDC}$  dBm/Hz. The ATU-R transmits at a power level of  $-38 - \text{UC}$  dBm/Hz. In this example, the ATUs both select the unknown profile during message exchanges of the fast retrain procedure.

**G.994.1**

- 6 The ATU-R initiates G.994.1 by transitioning to R-SILENT0 and transmitting R-TONES-REQ at  $-38 - \text{UC}$  dBm/Hz.
- 7 The ATU-C initiates G.994.1 by transitioning to C-SILENT1 and transmitting C-TONES at  $-40 - \text{DPF} - \text{RDC}$  dBm/Hz.
- 8 Both ATUs continue with the G.994.1 procedure and terminate it using a mode select transaction with a G.992.2 code point asserted. The escape to fast retrain bit is not asserted.

**Initialization Procedure**

- 9 Both ATUs observe the quiet period required at the start of the G.992.2 initialization procedure.
- 10 The ATU-C continues the initialization procedure by transmitting C-PILOT at  $-40 - \text{DPF} - \text{RDC}$  dBm/Hz.
- 11 The ATU-R responds by transmitting R-REVERB1 at  $-38 - \text{UC}$  dBm/Hz, and the ATU-C measures the received power in 12 tones to determine a new value of DPI = 0, 2, 4, 6, 8, 10, or 12 dB.
- 12 The ATU-C starts transmitting C-REVERB1 at  $-40 - 2n$ . The value of  $2n$  is the maximum of the value of  $(\text{DPF} + \text{RDC})$  and the value of DPI.
- 13 Both ATUs finish the initialization procedure and go to SHOWTIME. During the messages exchanged in this initialization procedure, the ATU-C informs the ATU-R of the DPI cutback that was determined (but the value  $2n$  is the absolute power cutback used by the ATU-C). Note that this is expected to be the same as the previous determination of DPI, but there could be variation.

**Second SHOWTIME**

14 During SHOWTIME, both ATUs save profile #1 using the aoc protocol.

This scenario conforms to G.992.2 for all cases of short and long loops. However, the effect of power cutback varies somewhat for each these cases. Examples are provided to clarify the effect of power cutback in these cases. Each example is summarized with a table that depicts the same state flow of both ATUs as shown in Figure II.2. The template for the example is shown in Table II.9. The apostrophe (') following names indicates the new values determined during the fast retrain and initialization procedures.

**Table II.9/G.992.2 – Summary of First Off-Hook Condition Scenario**

ATU-C Block	dBm/Hz	Steps	ATU-R Block	dBm/Hz
First SHOWTIME	$-40 - \max(\text{DPI}, \text{DPF} + \text{RDC}) + g_i$		First SHOWTIME	$-38 - \text{UC} + g_i$
Fast Retrain C-RECOV	-40	1-2	Fast Retrain R-RECOV	-38
First Portion of Fast Retrain	$-40 - \text{DPF}'$	3-4	First Portion of Fast Retrain	$\leq -38$
Remainder of Fast Retrain	$-40 - \text{DPF}' - \text{RDC}'$	5	Remainder of Fast Retrain	$-38 - \text{UC}'$
G.994.1	$-40 - \text{DPF}' - \text{RDC}'$	6-8	G.994.1	$-38 - \text{UC}'$
C-PILOT	$-40 - \text{DPF}' - \text{RDC}'$	9-11	R-REVERB1	$-38 - \text{UC}'$
C-REVERB1 and Remainder of Initialization Procedure	$-40 - \max(\text{DPI}', \text{DPF}' + \text{RDC}')$	12-13	Remainder of Initialization Procedure	$-38 - \text{UC}'$
SHOWTIME	$-40 - \max(\text{DPI}', \text{DPF}' + \text{RDC}') + g_i'$	14	SHOWTIME	$-38 - \text{UC}' + g_i'$

**Example with Long Loop**

During the scenario in this case, no politeness cutbacks are active. A numeric example of the various power levels is shown in Table II.10. In this example, the new values of RDC and UC are 4 and 18 dB, respectively. The previous values of RDC and UC are 0 and 6 dB, respectively.

**Table II.10/G.992.2 – Power Levels for Off-hook Operating Case with Long Loop**

ATU-C Block	dBm/Hz	ATU-R Block	dBm/Hz
First SHOWTIME	$-40 + g_i$	First SHOWTIME	$-44 + g_i$
Fast Retrain C-RECOV	-40	Fast Retrain R-RECOV	-38
First Part of Fast Retrain	-40	First Part of Fast Retrain	$\leq -38$
Remainder of Fast Retrain	-44	Remainder of Fast Retrain	-56
G.994.1	-44	G.994.1	-56
C-PILOT	-44	R-REVERB1	-56
C-REVERB1 and Remainder of Initialization Procedure	-44	Remainder of Initialization Procedure	-56
SHOWTIME	$-44 + g_i'$	SHOWTIME	$-56 + g_i'$

**Example with Short Loop**

During the scenario in this case, both politeness and fast retrain power cutbacks are active. A numeric example of the various power levels is shown in Table II.11. In this example, the new values of DPF and DPI are 6 and 8 dB, respectively. The new values of RDC and UC are 12 and 22 dB, respectively. The previous value of DPF and DPI are 10 and 6 dB, respectively. The previous values of RDC and UC are both 0.

**Table II.11/G.992.2 – Power Levels for Off-hook Operating Case with Short Loop**

ATU-C Block	dBm/Hz	ATU-R Block	dBm/Hz
First SHOWTIME	$-50 + g_i$	First SHOWTIME	$-38 + g_i$
Fast Retrain C-RECOV	-40	Fast Retrain R-RECOV	-38
First Part of Fast Retrain	-40	First Part of Fast Retrain	-38
Remainder of Fast Retrain	-58	Remainder of Fast Retrain	-60
G.994.1	-58	G.994.1	-60
C-PILOT	-58	R-REVERB1	-60
C-REVERB1 and Remainder of Initialization Procedure	-58	Remainder of Initialization Procedure	-60
SHOWTIME	$-58 + g_i$	SHOWTIME	$-60 + g_i'$

**Return to On-hook Condition**

This scenario describes a sequence that might occur following an off-hook condition as the telephone device returns to the on-hook condition. The ATUs have profiles #0 stored, and #0 is associated with the previous on-hook condition. A non-ideal telephone device without an in-line filter is assumed to go to its on-hook condition in this scenario.

For convenience in describing the scenario, the ATU state sequence is broken into several blocks as given in Table II.8. The step numbers in the table refer to the paragraph numbers that follow in this subclause.

**Table II.12/G.992.2 – Blocks of Return to On-Hook Scenario**

Block	Steps
First SHOWTIME	
Fast Retrain	1-5
Second SHOWTIME	6

The scenario proceeds as described in the steps below and as depicted in Figure II.3.

CO Transmitter Downstream		Block	Step	CP Transmitter Upstream	
dbm/Hz	State			dbm/Hz	State
$-40$ $-\max(\text{DPI}, \text{DPF} + \text{RDC})$ $+ g_i$	SHOWTIME	First SHOWTIME		$-38$ $-\text{UC}$ $+ g_i$	SHOWTIME
	C-RECOV		1		
	C-REVERB-FR1		2	$-38$	R-RECOV
$-40$ $-\text{DPF}'$	sequence of fast retrain states ending in C-CRC-FR1	Fast Retrain	3		
$-40$ $-\text{DPF}'$	sequence of fast retrain states starting with C-REVERB-FR3 and ending in C-SEGUE-FR4		4	$\leq -38$	sequence of fast retrain states ending in R-QUIET-FR1
$-40$ $-\text{DPF}' - \text{RDC}'$			5	$-38$ $-\text{UC}'$	sequence of fast retrain states starting with R-REVERB-FR3 and ending in R-SEGUE-FR5
$-40$ $-\text{DPF}' - \text{RDC}'$ $+ g_i'$	SHOWTIME	Second SHOWTIME	6	$-38$ $-\text{UC}$ $+ g_i$	SHOWTIME

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**Figure II.3/G.992.2 – Return to On-Hook Scenario**

### Fast Retrain

- 1 The ATU-R initiates the fast retrain procedure by transmitting R-RECOV signal at  $-38$  dBm/Hz. In this example, the ATU-C does not measure the received power of the tone to calculate DPF cutback as in the install scenario in First Successful On-hook Activation.
- 2 The ATU-C initiates the fast retrain procedure by transmitting C-RECOV signal at  $-40$  dBm/Hz.
- 3 The ATU-C transmits C-REVERB-FR1 at  $-40 - \text{DPF}$ . In this example, the ATU-C sets DPF to the previous value of DPI unlike the install scenario in First Successful On-hook Activation.
- 4 Both ATUs execute the first portion of the fast retrain procedure (through C-CRC-FR1 and R-QUIET-FR1). The ATU-C transmits at a power level of  $-40 - \text{DPF}$  dBm/Hz. The ATU-R transmits at a power level of  $-38$  dBm/Hz. During the messages exchanged in this fast retrain procedure, the ATU-R commands the ATU-C of the value of RDC that the ATU-C shall be used and informs the ATU-C of the value of UC that it shall use. The ATU-C informs the ATU-R of the value of DPF that it has been using.
- 5 Both ATUs complete the fast retrain. The ATU-C transmits at a power level of  $-40 - \text{DPF} - \text{RDC}$  dBm/Hz. The ATU-R transmits at a power level of  $-38 - \text{UC}$  dBm/Hz. In



this example, the ATUs both select profile #0 during message exchanges of the fast retrain procedure.

## Second SHOWTIME

- 6 Both ATUs return to SHOWTIME. The ATU-C transmits at a power level of  $-40 - \text{DPF} - \text{RDC}$  adjusted by the  $g_i$  tables from the profile #0. Note that this is different that the downstream PSD equation in First Successful On-hook Activation and First Off-hook Condition. The ATU-R transmits at a power level of  $-38 - \text{UC}$  adjusted by the  $g_i$  tables from the profile #0.

This scenario conforms to G.992.2 for all cases of short and long loops. However, the effect of power cutback varies somewhat for each these cases. Examples are provided to clarify the effect of power cutback in these cases. Each example is summarized with a table that depicts the same state flow of both ATUs as shown in Figure II.3. The template for the example is shown in Table II.13. The apostrophe (') following names indicates the new values determined during the fast retrain and initialization procedures.

**Table II.13/G.992.2 – Summary Return to On-Hook Scenario**

ATU-C Block	dBm/Hz	Steps	ATU-R Block	dBm/Hz
First SHOWTIME	$-40 - \max(\text{DPI}, \text{DPF} + \text{RDC}) + g_i$		First SHOWTIME	$-38 - \text{UC} + g_i$
Fast Retrain C-RECOV	$-40$	1-2	Fast Retrain R-RECOV	$-38$
First Portion of Fast Retrain	$-40 - \text{DPF}'$	3-4	First Portion of Fast Retrain	$\leq -38$
Remainder of Fast Retrain	$-40 - \text{DPF}' - \text{RDC}'$	5	Remainder of Fast Retrain	$-38 - \text{UC}'$
SHOWTIME	$-40 - \text{DPF}' - \text{RDC}' + g_i'$	6	SHOWTIME	$-38 - \text{UC}' + g_i'$

## Example with Long Loop

During the scenario in this case, politeness cutbacks are not active. A numeric example of the various power levels is shown in Table II.14. In this example, the new values of RDC and UC are 0. The previous values of DPI, DPF, RDC, and UC are 0, 0, 6, and 12 dB, respectively.

**Table II.14/G.992.2 – Power Levels for On-hook Operating Case with Long Loop**

ATU-C Block	dBm/Hz	ATU-R Block	dBm/Hz
First SHOWTIME	$-46 + g_i$	First SHOWTIME	$-50 + g_i$
Fast Retrain C-RECOV	$-40$	Fast Retrain R-RECOV	$-38$
First Portion of Fast Retrain	$-40$	First Portion of Fast Retrain	$\leq -38$
Remainder of Fast Retrain	$-40$	Remainder of Fast Retrain	$-38$
SHOWTIME	$-40 + g_i$	SHOWTIME	$-38 + g_i$

## Example with Short Loop

During the scenario in this case, both politeness and fast retrain power cutbacks are active. A numeric example of the various power levels is shown in Table II.15. In this example, the new values of DPF, RDC and UC are 4, 2, and 0. The previous values of DPI, DPF, RDC, and UC are 6, 4, 14, and 24 dB, respectively.

**Table II.15/G.992.2 – Power Levels for On-hook Operating Case with Short Loop**

ATU-C Block	dBm/Hz	ATU-R Block	dBm/Hz
First SHOWTIME	$-58 + g_i$	First SHOWTIME	$-62 + g_i$
Fast Retrain C-RECOV	-40	Fast Retrain R-RECOV	-38
First Portion of Fast Retrain	-44	First Portion of Fast Retrain	$\leq -38$
Remainder of Fast Retrain	-46	Remainder of Fast Retrain	-38
SHOWTIME	$-46 + g_i'$	SHOWTIME	$-38 + g_i'$

**Power Management Scenarios**

These scenarios represent situations that will normally occur while transitioning among the three defined power management states L0, L1, and L3 using the power management transitions described in this Recommendation.

**Retrain Scenarios**

While in L0 or L1 SHOWTIME states, line conditions or external commands may lead to the desire to retrain the modems. The special cases of off-hook and on-hook L0 to L0 transitions has already been presented in Normal Operating Scenarios where fast retrain is first attempted followed by initialization if necessary. This also applies to the scenario of L0 to L0 and L1 to L0 transitions that require retraining for other reasons. The fast retrain followed by initialization provides all necessary power cutbacks, allows the modems to quickly return to SHOWTIME if any stored profile matches, and provides full initialization if not.

**Wake-up Scenarios**

This situation occurs when one of the ATUs desires to wake the link from L3 state and return it to L0 state. Either ATU may initiate the wake-up procedure. If the initiating ATU has retained memory, it may begin with either the fast retrain procedure or the initialization procedure. If the initiating ATU has not retained memory, it will begin with the initialization procedure. If the responding ATU has lost memory, it will abort a fast retrain request and will begin the initialization procedure.

A summary of these combinations is presented in Table II.16 and details of the procedures are explained in the indicated paragraphs.

**Table II.16/G.992.2 – Scenarios for Waking from L3 Link State**

CO Memory	CP Memory	Initiator	Procedure First Used	Scenario
Retained	Retained	ATU-C	Initialization	Wake-up Starting with Initialization
		ATU-C	Fast Retrain	Wake-up Starting With Fast Retrain
		ATU-R	Initialization	Wake-up Starting with Initialization
		ATU-R	Fast Retrain	Wake-up Starting With Fast Retrain
Retained	Lost	ATU-C	Initialization	First Successful On-hook Activation
		ATU-C	Fast Retrain	ATU-R aborts fast retrain request and proceeds as in Wake-up Starting with Initialization
		ATU-R	Initialization	Wake-up Starting with Initialization

**Table II.16/G.992.2 – Scenarios for Waking from L3 Link State (concluded)**

CO Memory	CP Memory	Initiator	Procedure First Used	Scenario
Lost	Retained	ATU-C	Initialization	Wake-up Starting with Initialization
		ATU-R	Initialization	Wake-up Starting with Initialization
		ATU-R	Fast Retrain	ATU-C aborts fast retrain request and proceeds as in Wake-up Starting with Initialization
Lost	Lost	ATU-C	Initialization	Wake-up Starting with Initialization
		ATU-R	Initialization	Wake-up Starting with Initialization

**Wake-up Starting With Fast Retrain**

An ATU that has retained memory can begin the wake-up procedure using the fast retrain procedure. The ATU initiates either the C-RECOVER or R-RECOVER signals. The action taken by the responding ATU depends upon whether it has retained memory.

**Responding ATU Has Retained Memory**

If the responding ATU has retained memory, it will respond with the C-RECOVER or R-RECOVER signal at nominal G.992.2 power level and attempt to recall a stored profile to return to link state L0. If the result is the unknown profile, the initialization procedure will follow.

The scenario with the ATU-R initiating proceeds using exactly the same six steps as in Return to On-hook Condition. The state sequence is exactly as shown in Figure II.3, except that both ATUs start in a silent state. PSD levels to be used are as summarized in Table II.13.

If an unknown profile were selected by the fast retrain in this scenario, then G.994.1 and the G.992.2 initialization procedure would be invoked using the fast retrain power cutbacks to return to L0 SHOWTIME.

**Responding ATU Has Not Retained Memory**

If the responding ATU has not retained memory, there is little point to attempting to match a stored profile. However, the fast retrain procedure is useful to determine necessary power cutback levels. The ATU will respond with the C-RECOVER or R-RECOVER signal at nominal G.992.2 power levels and use the fast retrain truncate followed by the initialization procedure to return to the L0 link state.

The scenario with the ATU-R initiating proceeds using exactly the same steps starting with step 11 as in First Successful On-hook Activation. The state sequence is exactly as shown in Figure II.1 starting from step 11. Both ATUs start in a silent state prior to step 11. PSD levels to be used are as summarized in Table II.3.

**Wake-up Starting with Initialization**

If an ATU has not retained memory, it begins with the initialization procedure using G.994.1. Since it is unknown if the other side has retained memory, the responding G.994.1 power levels may not be G.992.2 nominal. Because of this, the procedure used for wake-up starting with initialization is as in First Successful On-hook Activation.

The scenario with the ATU-R initiating proceeds using exactly the steps as in First Successful On-hook Activation. The PSD levels to be used are as summarized in Table II.3.

**Error Recovery Scenarios**

These scenarios represent error conditions that may occur during the procedures.

**Unable to Install Scenario**

In this scenario, two ATUs are assumed attached to the line. However, they are unable to reach the SHOWTIME state because of some malfunction. In this example, the malfunction is one that comes during the initialization procedure's exchange sequence.

The scenario begins as in First Successful On-hook Activation. However, for this example, a malfunction occurs in step 21. The ATUs invoke the initialization reset procedure and begin G.994.1 at nominal power levels. Assuming the ATUs desire to attempt another connection, they again go through the sequence of First Successful On-hook Activation, except they may skip steps 1-5 because G.994.1 power levels are already known to be at nominal levels. This may continue for some time. If the SHOWTIME state cannot be reached repeatedly, the ATUs can use G.994.1 to select another common mode of operation or send a mode select command with all zero operation mode bits to terminate the attempts.

The use of fast retrain followed by initialization provides all necessary power cutbacks for the repeated attempts to train that may occur with phone devices in various hook switch conditions.

**Unable to Fast Retrain**

If a malfunction is detected while executing the fast retrain algorithm, the ATUs may either repeat the fast retrain a number of times or invoke the initialization procedure. Repeating the fast retrain a number of times may allow telephony device characteristics adequate settling time for the retrain to be successful. If continued malfunctions occur, the reset initialization procedure is invoked and the ATUs begin G.994.1 at nominal power levels. The ATUs again go through the sequence of First Successful On-hook Activation, except they may skip steps 1-5 because G.994.1 power levels are already known to be at nominal levels.

**SHOWTIME Error Recovery**

If a malfunction is detected while in SHOWTIME, the ATUs invoke either the fast retain procedure or the initialization reset procedure. When using the initialization reset procedure, the ATU's begin G.994.1 at nominal power levels. Assuming the ATUs desire to return to the L0 or L1 state, they go through the sequence of First Successful On-hook Activation, except they may skip steps 1-5 because G.994.1 power levels are already known to be at nominal levels.

**APPENDIX III****Compatibility with other Customer Premises Equipment**

G.992.2 CPE transceivers may share the CPE wiring plant with other equipment, e.g. networking devices.

Some networking devices can operate above 4 MHz on customer premises phone wiring. To prevent signals from such networking devices from aliasing into the G.992.2 frequency band, the inclusion of an adequate downstream receiver anti-aliasing filter in the G.992.2 device is recommended, collocated with the h-p filter in Figure 1. This filter may take the form of an external, in-line filter or may be integrated into the G.992.2 device.

If a POTS splitter is used in the G.992.2 application to isolate the customer premises wiring from the ADSL signal as noted in Figure 1, then home networking devices may co-exist with voice terminals and non-voice terminals on the TELE/POTS port side (the port in Figure 1 that attaches to the wire leading to the telephone set or voice band modem) of the remote splitter. It is desirable in those cases that the remote POTS splitter be compatible with other customer premises wiring devices (e.g. the TELE/POTS port impedance above 4 MHz should be considered).

Similarly, if an in-line low-pass filter is used in the G.992.2 application as shown in Figure 1, it is desirable that the in-line low-pass filter be compatible with other customer premises wiring devices (e.g. the in-line filter impedance above 4 MHz should be considered).





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# **EXHIBIT 20**

**IN THE UNITED STATES DISTRICT COURT  
FOR THE DISTRICT OF DELAWARE**

<p>TQ DELTA, LLC,</p> <p style="text-align: right;">Plaintiff,</p> <p style="text-align: center;">v.</p> <p>2WIRE, INC.</p> <p style="text-align: right;">Defendant.</p>	Civil Action No. 13-cv-1835-RGA
<p>TQ DELTA, LLC,</p> <p style="text-align: right;">Plaintiff,</p> <p style="text-align: center;">v.</p> <p>ZHONE TECHNOLOGIES, INC.</p> <p style="text-align: right;">Defendant.</p>	Civil Action No. 13-cv-1836-RGA
<p>TQ DELTA, LLC,</p> <p style="text-align: right;">Plaintiff,</p> <p style="text-align: center;">v.</p> <p>ZYXEL COMMUNICATIONS, INC. and ZYXEL COMMUNICATIONS CORPORATION,</p> <p style="text-align: right;">Defendants.</p>	Civil Action No. 13-cv-2013-RGA
<p>TQ DELTA, LLC,</p> <p style="text-align: right;">Plaintiff,</p> <p style="text-align: center;">v.</p> <p>ADTRAN, INC.</p> <p style="text-align: right;">Defendant.</p>	Civil Action No. 14-cv-954-RGA
<p>ADTRAN, INC,</p> <p style="text-align: right;">Plaintiff,</p> <p style="text-align: center;">v.</p> <p>TQ DELTA, LLC.</p> <p style="text-align: right;">Defendant.</p>	Civil Action No. 15-cv-121-RGA

**FAMILY 3 - DEFENDANTS' DISCLOSURE OF CLAIM TERMS FOR  
CONSTRUCTION AND PROPOSED DEFINITIONS**

Pursuant to the Third and Final Scheduling Order entered in this Action, Defendants 2Wire, Inc., Zhone Technologies, Inc., ZyXEL Communications, Inc., ZyXEL Communications Corp., and AdTRAN, Inc. (collectively, "Defendants") propose that the following terms and phrases appearing in Plaintiff TQ Delta, LLC's ("TQ Delta") U.S. Patent Nos. U.S. Patent No. 7,831,890 (the "'890 patent"); U.S. Patent No. 7,836,381 (the "'381 patent"); U.S. Patent No. 7,844,882 (the "'882 patent"); U.S. Patent No. 8,276,048 (the "'048 patent"); and U.S. Patent No. 8,495,473 (the "'473 patent") (collectively, the "Family 3 Patents") be construed.

Defendants also provide their proposed constructions for each respective term.

Defendants reserve the right, inter alia, to modify or supplement this disclosure to facilitate agreement with TQ Delta to avoid duplication of terms or phrases, to reflect newly received information and discovery or to reflect changes in TQ Delta's contentions.

Furthermore, Defendants reserve the right to amend their proposed claim terms and phrases for construction once they have had an opportunity to review TQ Delta's proposed terms and phrases for construction and their respective proposed definitions. Defendants reserve the right to propose a construction for any term identified by TQ Delta now, or at any other time during claim construction. TQ Delta has not served rules-compliant final infringement contentions that demonstrate how Defendants' accused products allegedly infringe each limitation of each of TQ Delta's asserted claims, and Defendants' proposed terms and claim constructions are made based on TQ Delta's infringement contentions to date. Defendants reserve the right to revise their proposed terms and constructions based on any infringement contentions later served by TQ Delta. Defendants reserve the right to assert that the preambles of the Family 3 Patents are limiting. Defendants further reserve the right to assert that any of the terms contained in asserted



claims are indefinite under 35 U.S.C. § 112.

Defendants are prepared to meet and confer with TQ Delta at a mutually agreeable time to exchange proposed constructions for terms disclosed by TQ Delta, but not by Defendants, and to narrow the terms in need of construction and the disputes over construction. The list of terms and phrases provided below is not necessarily intended as an indication that any such term or phrase should have a construction that is different from its common and ordinary meaning.

Defendants anticipate that the parties may be able to narrow the list of terms and phrases to be construed during the process culminating in the filing of a Joint Claim Construction Statement.

<b>Claim Term</b>	<b>Patents &amp; Claims</b>	<b>Proposed Definition</b>
“transceiver”	’890 patent, claim 5; ’381 patent, claim 5; ’882 patent, claim 13; ’048 patent, claim 1; ’473 patent, claim 19, 28	“communications device capable of transmitting and receiving data”
“shared memory”	’890 patent, claims 5; ’381 patent, claim 5; ’882 patent, claim 13; ’048 patent, claim 1	“single common memory in a transceiver used by both an interleaver in a transmitter latency path and a deinterleaver in a receiver latency path”
“amount of memory”	’890 patent claim 5; ’381 patent, claim 5; ’882 patent, claim 13; ’048 patent, claim 1	“number of bytes of memory”
“portion of the memory”	’473 patent, claims 19, 28	“number of bytes within the memory”
“latency path”	’473 patent, claims 19, 28	“distinct transmit or receive path”
“the shared memory allocated to the [deinterleaver/interleaver] is used at the same time as the shared memory allocated to	’890 patent, claim 5; ’381 patent, claim 5; ’882 patent, claim 13; ’048 patent, claim 1	“the deinterleaver reads from or writes to its respective allocation of the shared memory at the same time as the interleaver reads from or writes to its respective

the [interleaver/deinterleaver]”		allocation of the shared memory”
“wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the message”	’473 patent, claim 19	“wherein at least a number of bytes within the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time depending on the amounts of memory specified in the message”
“wherein the generated message indicates how the memory has been allocated between the interleaving function and the deinterleaving function”	’473 patent, claim 28	“wherein the generated message indicates a number of bytes of memory allocated to the interleaving function and a number of bytes of memory allocated to the deinterleaving function”

May 3, 2017

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**CERTIFICATE OF SERVICE**

I, Rachel M. Walsh, hereby certify that on May 3, 2017, a copy of FAMILY 3 -  
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PROPOSED DEFINITIONS was served on the following as indicated:

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